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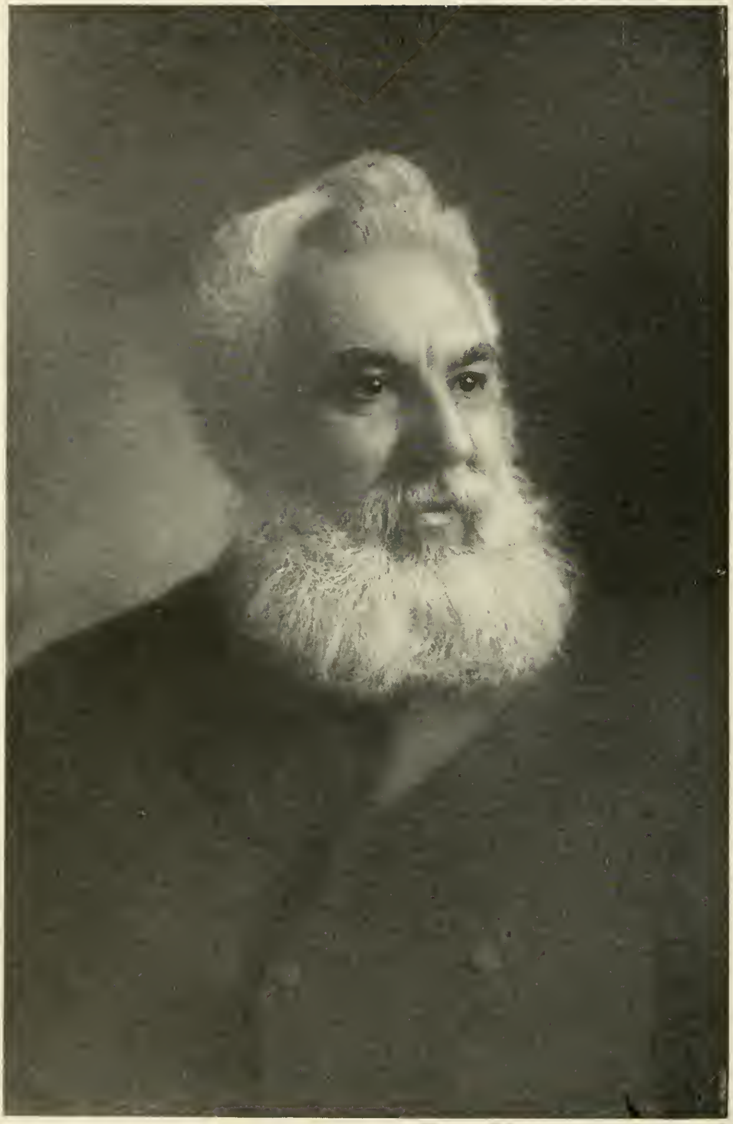

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Applied Electricity

A General Reference Work on

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Prepared by a Corps of

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SEVEN VOLUMES

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Grateful acknowledgment is here made also for the invaluable co-operation of the foremost engineering firms and manufacturers in making these volumes thoroughly representative of the very best and latest practice in the design, construction, and operation of electrical machinery and instruments; also for the valuable drawings, data, suggestions, criticisms, and other courtesies.

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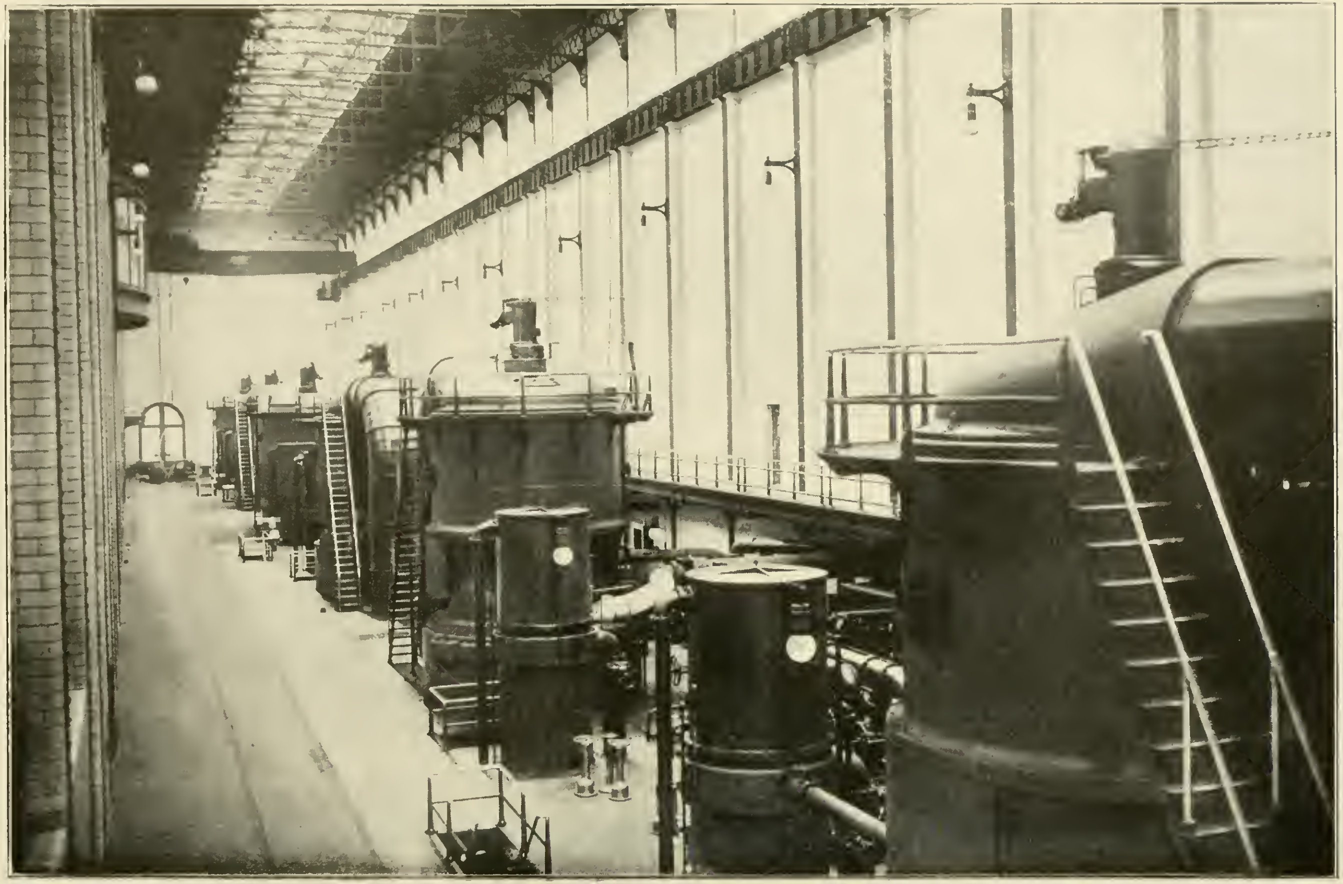

VIEW OF QUARRY STREET POWER STATION, COMMONWEALTH EDISON COMPANY
Installation consists of six vertical Curtiss turbines of 21,000 horsepower each
Courtesy of Commonwealth Edison Company

Foreword

ONE of the simplest acts in modern life is switching on the electric current that gives light or power, or that makes possible communication between distant points. A child can perform that act as effectively as a man, so thoroughly has electricity been broken to the harness of the world's work; but behind that simple act stand a hundred years of struggle and achievement, and the untiring labors of thousands of the century's greatest scientists. To compact the results of these labors into the compass of a practical reference work is the achievement that has been attempted — and it is believed accomplished—in this latest edition of the Cyclopedia of Applied Electricity.

¶ Books on electrical topics are almost as many as the subjects of which they treat, and all of them, if gathered into a great common library, would contain so many duplicate pages that their use would entail an appalling waste of time upon the man who is trying to keep up with electrical progress. To overcome this difficulty the publishers of this Cyclopedia went direct to the original sources, and secured as writers of the various sections, men of wide practical experience and thorough technical training, each an acknowledged authority in his work; and these contributions have been correlated by our Board of Editors into a logical and unified whole.

¶ The Cyclopedia is, therefore, a complete and practical working treatise on the generation and application of electric power.

It covers the known principles and laws of Electricity, its generation by dynamos operated by steam, gas, and water power; its transmission and storage; and its commercial application for purposes of power, light, transportation, and communication. It includes the construction as well as the operation of all plants and instruments involved in its use; and it is exhaustive in its treatment of operating "troubles" and their remedies.

¶ The Cyclopedia is as thoroughly scientific as any work could be; but its treatment is as free as possible from abstruse mathematics and unnecessary technical phrasing, while it gives particular attention to the careful explanation of involved but necessary formulas. Diagrams, curves, and practical examples are used wherever they may be helpful in explaining the subject under discussion.

¶ The Cyclopedia is a compilation of many of the most valuable Instruction Books of the American School of Correspondence, and the method adopted in its preparation has been found to be the best devised for the education of the busy, practical man.

¶ A glossary of the electrical terms used in this Cyclopedia will be found in Volume VII. The definitions are given in simple language and, where it was thought desirable, reference has been made to the volume and page where the reader may find added matter on the topic sought.

¶ Attention is directed to a bibliography of the best literature in Electrical Engineering, in Volume VII. No attempt has been made to exhaust the sources but merely to provide the names, authors, and publishers of books which would appeal to the widest circle of readers.

¶ In conclusion, grateful acknowledgment is due to the staff of authors and collaborators, without whose hearty co-operation this work would have been impossible.

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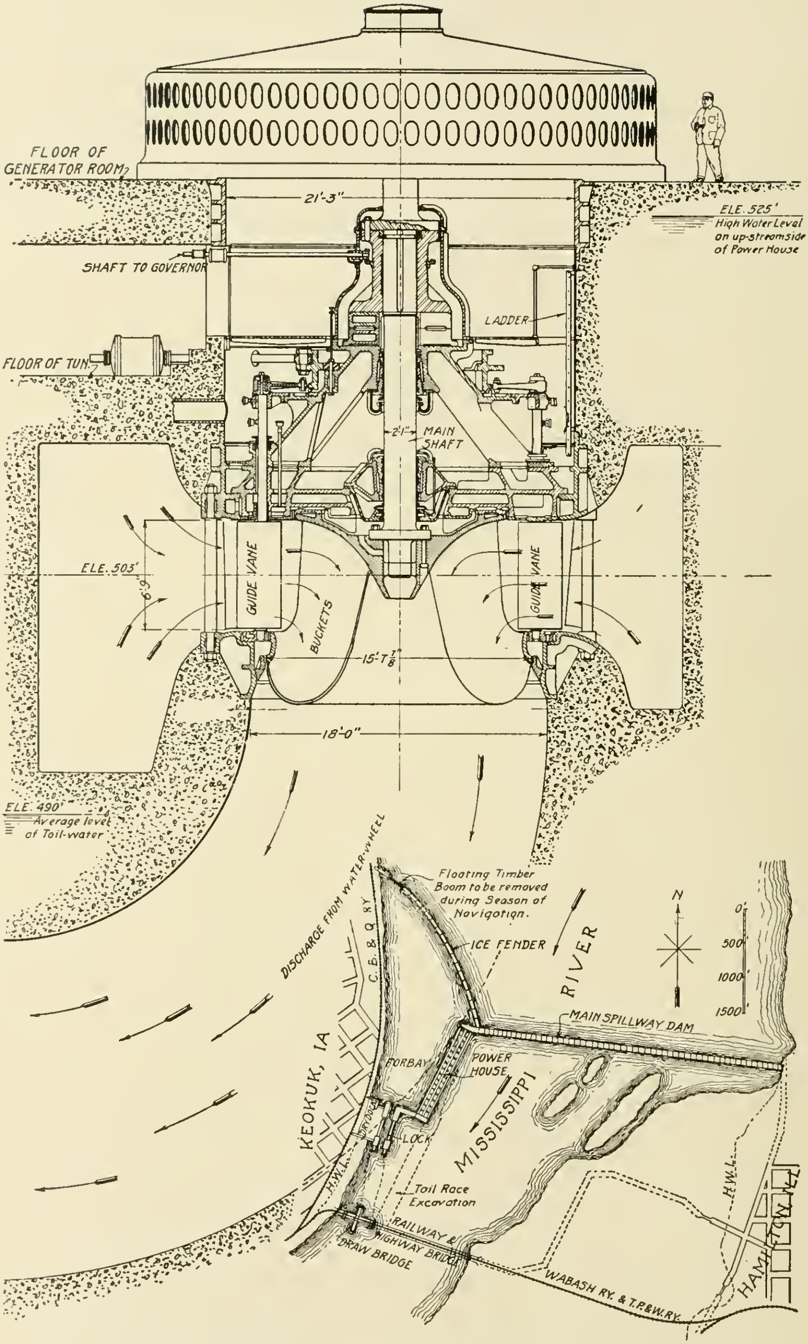

SECTION OF ONE OF THE TURBINES INSTALLED IN THE MISSISSIPPI POWER COMPANY'S PLANT AT KEOKUK

Thirty such turbines, each furnishing over 10,000 horsepower, represent the capacity of the plant when completed. The lower diagram shows plan of the entire development

Courtesy of Mississippi River Power Company

POWER STATIONS

INTRODUCTION

With the rapid increase of the use of electricity for power, lighting, traction, and electro-chemical processes, the power houses equipped for the generation of the electrical supply have increased in size from plants containing a few low-capacity dynamos, belted to their prime movers and lighting a limited district, to the modern central station, furnishing power to immense systems and over extended areas. Examples of the latter type of station are found at Niagara Falls, and such stations as the Metropolitan and Manhattan stations in New York City, and the plants of the Boston Edison Illuminating Company, etc.

The subject of the design, operation, and maintenance of central stations forms an extended and attractive branch of electrical engineering. The design of a successful station requires scientific training, extensive experience, and technical ability. Knowledge of electrical subjects alone will not suffice, as civil and mechanical engineering ability is called into play as well, while ultimate success depends largely on financial conditions. Thus, with unlimited capital, a station of high economy of operation may be designed and constructed, but the business may be such that the fixed charges for money invested will more than equal the difference between the receipts of the company and the cost of the generation of power alone. In such cases it is better to build a cheaper station and one not possessing such extremely high economy, but on which the fixed charges are so greatly reduced that it may be operated at a profit to the owners.

The designing engineer should be thoroughly familiar with the nature and extent of the demand for power and with the probable increase in this demand. Few systems can be completed for their ultimate capacity at first and, at the same time, be operated economically. Only such generating units, with suitable reserve capacity, as are necessary to supply the demand should be installed at first, but all apparatus should be arranged in such a manner that future extensions can readily be made.

Power stations, as here treated, will be considered under the following general topics:

Location of Station
Steam Plant
Hydraulic Plant
Gas Plant
Electric Plant
Buildings
Station Records

LOCATION OF STATION

The choice of a site for the generating station is very closely connected with the selection of the system to be used, which system, in turn, depends largely on the nature of the demand, so that it is a little difficult to treat these topics separately. Several possible sites are often available, and we may either consider the requirements of an ideal location, selecting the available one which is nearest to this in its characteristics, or we may select the best system for a given area and assume that the station may be located where it would be best adapted to this system. Wherever the site may be, it is possible to select an efficient system, though not always an ideal one.

The points that should be considered in the location of a station, no matter what the system used, are accessibility, water supply, stability of foundations, surroundings, facility for extension, and cost of real estate.

Accessibility. The station should be readily accessible on account of the delivery of fuel, of stores, and of machinery. It should be so located that ashes and cinders may easily be removed. If possible, the station should be located so as to be reached by both rail and water, though the former is generally more desirable. If the coal can be delivered to the bunkers directly from the cars, the very important item of the cost of handling fuel may be greatly reduced. Again, the station should be in such a location that it may readily be reached by the workmen.

Water Supply. Cheap and abundant water supply for both boilers and condensers is of utmost importance in locating a steam station. The quality of the water supply for the boiler is of more importance than the quantity. It should be as free as possible from impurities which are liable to corrode the boilers, and for this reason water from the town mains is often used, even when other water is available, as it is possible to economize in the use of water by the selection of proper condensers. The supply for condensing purposes should be abundant, otherwise it is necessary to install extensive cooling apparatus, which is costly and occupies much space.

Stability of Foundations. The machinery, as well as the buildings, must have stable foundations, and it is well to investigate the availability of such foundations when selecting the site.

Surroundings. In the operation of a power plant using coal or other fuels, certain nuisances arise, such as smoke, noise, vibration, etc. For this reason it is preferable to locate where there is little liability to complaint on account of these causes, as some of these nuisances are costly and difficult, or even impossible, to prevent.

Facility for Extension. A station should be located where there are ample facilities for extension and, while it may not always be advisable to purchase land sufficient for these extensions at first, if there is the slightest doubt in regard to being able to purchase it later, it should be bought at once, as the station should be as free as possible from risk of interruption of its plans. Often real estate is too high for purchasing a site in the best location, and then the next best point must be selected. A consideration of all the factors involved is necessary in determining whether or not this cost is too high. In densely populated districts it is necessary to economize greatly with the space available, but it is generally desirable that all the machinery be placed on the ground floor and that adequate provision be made for the storage of fuel, etc. .

Cost of Real Estate. The location of substations is usually fixed by other conditions than those which determine the site of the main power house. Since, in the simple rotary-converter substation, neither fuel nor water is necessary, and there is little noise or vibration, it may be located wherever the cost of real estate will permit, provided suitable foundations may be constructed. The distance between substations depends entirely on the selection of the system and the nature of the service.

GENERAL FEATURES

Miscellaneous Considerations. Where low voltages are used, it is essential that the station be located as near the center of the system as possible. This center is located as follows:

Having determined the probable loads and their points of application for the proposed system, these loads are indicated on a drawing with the location of the same shown to scale. The center of gravity of this system, considering each load as a weight, is then found and its location is the ideal location, as regards amount of copper necessary for the distributing system.

Consider Fig. 1, which shows the location of five different loads, indicated in this case by the number of amperes. Combining loads A and B, we have

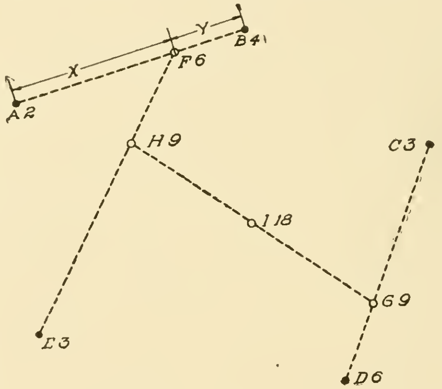

Fig. 1. Graphical Method of Locating Center of the System

$$Ax = By \qquad x + y = a$$

Solving these equations, we find that A and B may be considered as a load of $A + B$ amperes at F. Similarly, C and D, E and F, and G and H may be combined giving us I, the center of the system. The amount of copper necessary for a given regulation runs up very rapidly as the distance of the station from this point increases. Where there are obstructions which will not permit the feeders to be run in an approximately straight line, the distance $A\ B$, etc., should be measured along the line the conductors must take.

Selection of System. General rules only can be stated for the selection of a system to be used in any given territory for a certain class of service.

For an area not over two miles square and a site reasonably near the center, direct-current, low-pressure, three-wire systems may be used for lighting and ordinary power purposes. Either 220 volts or 440 volts may be used as a maximum voltage, and motors should, preferably, be connected across the outside wires of the circuits. Five-wire systems with 440 volts maximum potential have been used, but they require very careful balancing of the load if the service is to be satisfactory. 220-volt lamps are giving good satisfaction; moderate-size, direct-current motors may readily be built for this pressure and constant-potential arc lamps may be operated on this voltage, though not so economically as on 110 volts, if single lamps are used. The new types of incandescent lamps in low candle-power units are not suitable for 220 volts. For direct-current railway work, the limit of the distance to which power may be economically delivered with an initial pressure of 600 volts is from five to seven miles, depending on the traffic.

If the area to be served is materially larger than the above, or distances for direct-current railways greater, either of the two following schemes may be adopted: (1) Several stations may be located in the territory and operated separately or in multiple on the various loads; or (2) one large power house may be erected and the energy transmitted from this station at a high voltage to various transformers or transformer substations which, in turn, transform the voltage to one suitable for the receivers. Local conditions usually determine which of these two shall be used. The alternating-current system with a moderate potential—about 2,300 volts for the primary lines—is now often installed for very small lighting systems.

The use of several low-tension stations operating in multiple is recommended only under certain conditions, namely, that the demand is very heavy and fairly uniformly distributed throughout the area, and suitable sites for the power house can readily be obtained. Such conditions rarely exist and it is a question whether or not the single station would not be just as suitable for such cases as where the load is not so congested.

One reason why a large central station is preferred to several smaller stations is that large stations can be operated more economically, owing to the fact that large units may be used and they can be run more nearly at full load. There is a gain in the cost of attendance, and labor-saving devices can be more profitably installed. The location of the power plant is not determined to such a large extent by the position of the load, but other conditions, such as water supply, cheap real estate, etc., will be the governing factors. In several cities, notably New York, Chicago, and Boston, large central stations are being installed to take the place of several separate stations, the old stations being changed from generating power houses to rotary-converter substations. Both direct-current low-tension machines—for supplying the neighboring districts—and high-tension alternating-current machines—for supplying the out, lying or residence districts—are often installed in the one station.

As examples of the central station located at some distance from the center of the load, we have nearly all of the large hydraulic power developments. Here it is the cheapness of the water power which determines the power-house location. The greatest distance over which power is transmitted electrically at present is in the neighborhood of 200 miles.

If a high-tension alternating-current system is to be installed, there remains the choice of a polyphase or single-phase machine as well as the selection of voltage for transmission purposes. As pointed out in "Power Transmission," polyphase generators are cheaper than single-phase generators and, if necessary, they can be loaded to about 80 per cent of their normal capacity, single-phase, while motors can more readily be operated from polyphase circuits. If synchronous motors or rotary converters are to be installed, a polyphase.system is necessary. The voltage will be determined by the distance of transmission, care being taken to select a value considered as standard, if possible. Generators are wound giving a voltage at the terminals as high as 15,000 volts, but in many districts it is desirable to use step-up transformers for voltages above 6,600 on account of liability to troubles from lighting.

With the development of the single-phase railway motor, central stations generating single-phase current only, are occasionally built in larger sizes than previously, as their use heretofore has been limited to lighting stations.

Factors in Design. A few general notes in regard to the design of plants will be given here, the several points being taken up more in detail later.

Direct driving of apparatus is always superior to methods of gearing or belting as it is efficient, safe, and reliable, but it is not as flexible as shafting and belts, and on this account its adoption is not universal.

Speeds to be used will depend on the type and size of the generating unit. Small machines are always cheaper when run at high speeds, but the saving is less on large generators. For large engines slow speed is always preferable.

It is desirable that there be a demand for both power and lighting, and a station should be constructed which will serve both purposes. The use of power will create a day load for a lighting station, which does much to increase its ultimate efficiency and, as a rule, its earning capacity.

In addition to generator capacity necessary to supply the load, a certain amount of reserve, either in the way of additional units or overload capacity, must be installed. The probable load for, say three years, can be closely estimated, and this, together with the proper reserve, will determine the size of the station. The plant as a whole, including all future extensions, should be planned at the start as extensions will then be greatly facilitated. Usually it will not be desirable to begin extensions for at least three years after the first part of the plant has been erected.

Enough units must be installed so that one or more may be laid off for repairs, and there are several arguments in favor of making this reserve in the way of overload capacity, for the generators at least. Some of these arguments are:

Reserve is often required at short notice, notably in railway plants.

With overload capacity the rapid increase of load, such as occurs in lighting stations when darkness comes on suddenly, may more readily be taken care of.

There is always a factor of safety in machines not running to their fullest capacity.

Reserve capacity is cheaper in this form than if installed as separate machines.

As a disadvantage, we have a lower efficiency, due to machines not usually running at full load, but in the case of generators this is very slight.

TABLE I

Permissible Overload 33 Per Cent

	Machines added one at a time		Machines added two at a time		Machines added three at a time	
	No.	Size.	No.	Size.	No.	Size.
Initial installment	4	500	4	500	4	500
First extension	1	666	2	1000	3	2000
Second extension	1	888	2	2000	5	5000
Third extension	1	1183	2	4000	4	5000
Fourth extension	1	1577	4	4000		
Fifth extension	1	2103	8	4000		
Sixth extension	1	2804				

With an overload capacity of $33\frac{1}{3}$ per cent, four machines should be the initial installment, since one can be laid off for repairs, if necessary, the total load being readily carried by three machines. In planning extensions, the fact that at least one machine may require to be laid off at any time should not be lost sight of, while the units should be made as large as is conducive to the best operation.

Table I is worked out showing the initial installment for a 2,000-kw. plant with future extensions. It is seen from this table that adding two machines at a time gives more uniformity in the size of units—a very desirable feature.

The boilers should be of large units for stations of large capacity, while for small stations they must be selected so that at least one may be laid off for repairs.

STEAM PLANT

BOILERS

The majority of power stations have as their prime movers either steam or water power, though there are many using gas. If steam is the power selected, the subject of boilers is one of vital importance to the successful operation of central stations. The object of the boiler with its furnace is to abstract as much heat as possible from the fuel and impart it to the water. The various kinds of boilers used for accomplishing this more or less successfully are described in books on boilers, and we will consider here the merits of a few of the types only as regards central-station operation.

The considerations are: (1) Steam must be available throughout the twenty-four hours, the amount required at different parts of the day varying considerably. Thus, in a lighting station, the demand from midnight to 6 A. M. is very light, but toward evening, when the load on the station increases very rapidly, there is an abrupt increase in the rate at which steam must be given off. The maximum demand can readily be anticipated under normal weather conditions, but occasionally this maximum will be equaled or even exceeded at unexpected moments. For this reason a certain number of boilers must be kept under steam constantly, more or less of them running with banked fires during light loads. If the boilers have a small amount of radiating surface, the loss during idle hours will be decreased.

(2) The boilers must be economical over a large range of rates of firing and must be capable of being forced without detriment. Boilers should be provided which work economically for the hours just preceding and following the maximum load while they may be forced, though running at lower efficiency, during the peak.

(3) Coming to the commercial side of the question, we have first cost, cost of maintenance, and space occupied. The first cost, as does the cost of maintenance, varies with the type and the pressure of the boiler. The space occupied enters as a factor only when the situation of the station is such that space is limited, or when the amount of steam piping becomes excessive. In some city-plants, space may be the determining feature in the selection of boilers.

Classification. Boilers for central stations may be classified as fire-tube and water-tube types. Of the former may be mentioned the Cornish, Lancashire, Galloway, multitubular, marine, and economic boilers. The Babcock and Wilcox, Stirling, and Heine boilers are examples of the water-tube type.

Fire-Tube Boilers. The *Cornish and Lancashire* boilers have the fire tubes of such a diameter that the furnaces may be constructed inside of them. They differ only in the number of cylindrical tubes in which the furnaces are placed, as many as three tubes being placed in the largest sizes (seldom used) of the Lancashire boilers. They are made up to 200-pound steam pressure and possess the following features:

1. High efficiency at moderate rates of combustion
2. Low rate of depreciation
3. Large water space
4. Easily cleaned
5. Large floor space required
6. Cannot be readily forced

The *Galloway boiler* differs from the Lancashire boiler in that there are cross-tubes in the flues.

In the *multitubular boiler,* the number of tubes is greatly increased and their size is diminished. Their heating surface is large and they steam rapidly. They require a separate furnace and are used extensively for power-station work.

Marine boilers require no setting. Among their advantages and disadvantages may be mentioned:

1. Exceedingly small space necessary
2. Radiating surface reduced
3. Good economy
4. Heavy and difficult to repair
5. Unsuitable for bad water
6. Poor circulation of water

The economic boiler is a combination of the Lancashire and multitubular boilers, as is the marine boiler. It is set in brickwork and arranged so that the gases pass under the bottom and along the sides of the boiler as well as through the tubes. It way be compared with other boilers from the following points:

1. Small floor space
2. Less radiating surface than the Lancashire boiler
3. Not easily cleaned
4. Repairs rather expensive
5. Requires considerable draft

Water-Tube Boilers. The chief characteristics of the water-tube boilers, of which there are many types, are

1. Moderate floor space
2. Ability to steam rapidly
3. Good water circulation
4. Adapted to high pressure
5. Easily transported and erected
6. Easily repaired
7. Not easily cleaned
8. Rate of deterioration greater than for Lancashire boiler
9. Small water space, hence variation in pressure with varying demands for steam
10. Expensive setting

Initial Cost. As regards first cost, boilers installed for 150-pound pressure and the same rate of evaporation, will run in the following order: Galloway and Marine, highest first cost, Economic, Lancashire, and Babcock and Wilcox. The increase of cost, with increase of steam pressure, is greatest for the Economic and least for the water-tube type.

Deterioration. Deterioration is less with the Lancashire boiler than with the other types.

Floor Space. The floor space occupied by these various types built for 150 pounds pressure and 7,500 pounds of water, evaporated per hour, is given in Table II.

TABLE II

Boiler Floor Space

Kind of Boiler	Floor Space in sq. ft.
Lancashire	408
Galloway	371
Babcock and Wilcox	200
Marine wet-back	120
Economic	210

Efficiency. The percentage of the heat of the fuel utilized by the boiler is of great importance, but it is difficult to get reliable data in regard to this. Table III* will give some idea of the efficiencies of the different types. The efficiency is more a question of proper proportioning of grate and heating surface and condition of boiler than of the type of boiler. Economizers were not used in any of these tests, but they should always be used with the Lancashire type of boiler.

It is well to select a boiler from 20 to 50 pounds in excess of the pressure to be used, as its life may thus be considerably extended, while, when the boiler is new, the safety valve need not be set so near the normal pressure, and there is less steam wasted by the blowing off of this valve. Again, a few extra pounds of steam may be carried just previous to the time the peak of the load is expected. For pressures exceeding 200 or, possibly, 150 pounds, a water-tube boiler should be selected.

In large stations, it is preferable to make the boiler units of

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*From Donkin's "Heat Efficiency of Steam Boilers."

TABLE III

Boiler Efficiencies

Kind of Boiler	No. of Experiments	Mean Efficiency of Two Best Experiments	Lowest Efficiency	Mean Efficiency of All Experiments
Lancashire hand-fired	107	79.5	42.1	62.3
Lancashire machine-fired	40	73.0	51.9	64.2
Cornish hand-fired	25	81.7	53.0	68.0
Babcock and Wilcox hand-fired	49	77.5	50.0	64.9
Marine wet-back hand-fired	6	69.6	62.0	66.0
Marine dry-back hand-fired	24	75.7	64.7	69.2

large capacity, to do away as much as possible with the extra piping and fittings necessary for each unit. Water-tube boilers are best adapted for large sizes. These may be constructed for 150-pound pressure, large enough to evaporate 20,000 pounds of water per hour, at an economical rate.

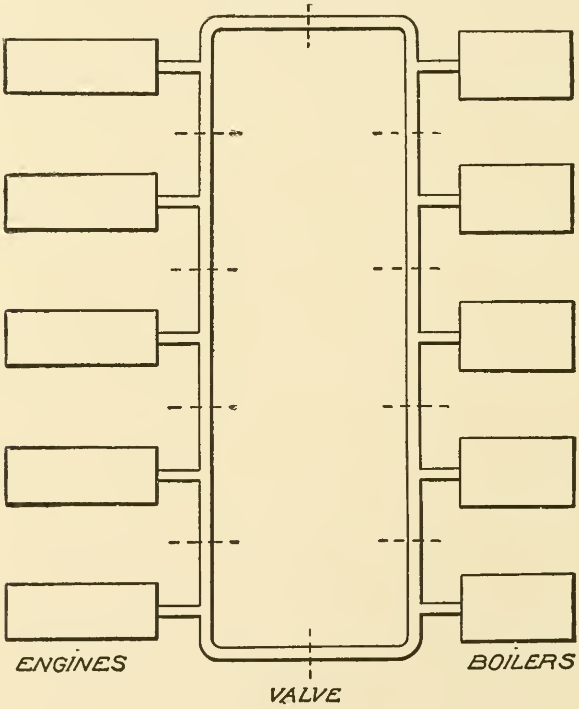


Fig. 2. Diagram of *Ring* System of Piping

Boilers of the multitubular type or water-tube boilers are used in the majority of power stations in the United States. For stations of moderate size, with medium steam pressures and plenty of space, the return tubular boiler is often employed. For the larger stations and the higher steam pressures, the water-tube boilers are employed. Marine or other special types are used only occasionally where space is limited or where other local conditions govern.

Steam Piping. The piping from the boilers to the engines should be given very careful consideration. Steam should be available at all times and for all engines. Freedom from serious interruptions due to leaks or breaks in the piping is brought about by very careful design and the use of good material in construction.

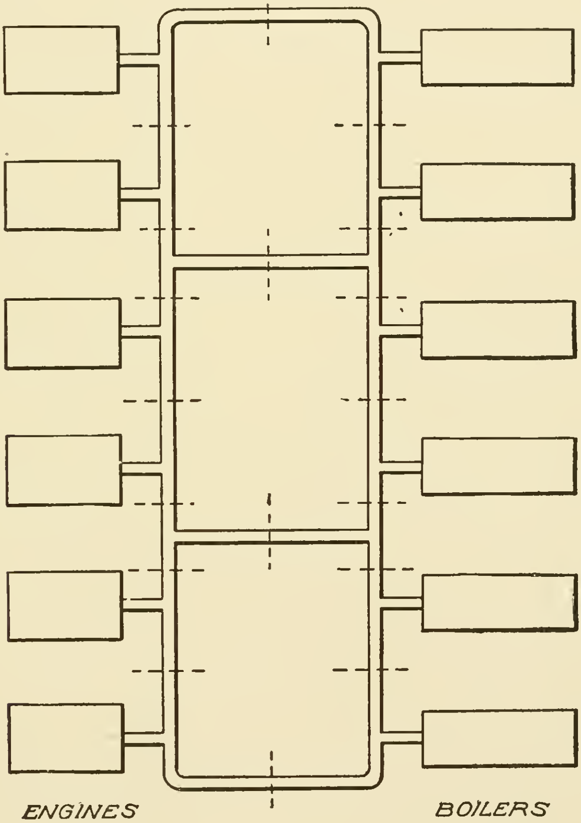


Fig. 3. Diagram of *Ring* System with Cross-Connections

Duplicate piping is used in many instances. Provision must always be made for variations in length of the pipe with variation of temperature. For plants using steam at 150-pound pressure, the variation in the length of steam pipe may be as high as 2.5 inches for 100 feet, and at least 2 inches for 100 feet should always be counted upon.

Arrangement. Fig. 2 shows a simple diagram of the *ring system* of piping. The steam passes from the boiler by two paths to the engine and any section of the piping may be cut out by the closing of two valves. Simple ring systems have the following characteristics:

1. The range, as the main pipe is called, must be of uniform size and large enough to carry all of the steam when generated at its maximum rate.
2. A damaged section may disable one boiler or one engine.
3. Several large valves are required.
4. Provision may readily be made to allow for expansion of pipes.

Cross-connecting the ring system, as shown in Fig. 3, changes these characteristics as follows:

1. Size of pipes and consequent radiating surface is reduced.
2. More valves are needed but they are of smaller size.
3. Less easy to arrange for expansion of the pipes.

If the system is to be duplicated, that is, two complete sets of main pipes and feeders installed, Fig. 4, two schemes are in use:

1. Each system is designed to operate the whole station at maximum load with normal velocity and loss of pressure in the pipes, and only one system is in use at a time. This has the disadvantage that the idle section is liable not to be in good operating condition when needed. Large pipes must be used for each set of mains.
2. The two systems may be made large enough to supply steam at normal loss of pressure when both are used at the same time, while either is made large enough to keep the station running should the other section need repairs. This has the advantages of less expense, and both sections of pipe are normally in use; but it has the disadvantages of more radiating surface to the pipes and consequent condensation for the same capacity for furnishing steam.

Complete interchangeability of units cannot be arranged for if the separate engine units exceed 400 to 500 horse-power. Since engine units can be made larger than boiler units, it becomes necessary to treat several boiler units as a single unit, or battery, these batteries being connected as the single boilers already shown. For still larger plants the steam piping, if arranged to supply any engines from any batteries of boilers, would be of enormous size. If the boilers do not occupy a greater length of floor space than the engines, Fig. 5 shows a good arrangement of units. Any engine can be fed from either of two batteries of boilers and the liability of serious interruptions of service due to steam pipes or boiler trouble is very remote.

In many plants but a single steam range is used, the station depending upon good material, careful construction, and thorough inspection for reliability of service. In the largest steam-turbine stations, the so-called unit system is employed as is explained later under "Station Arrangement."

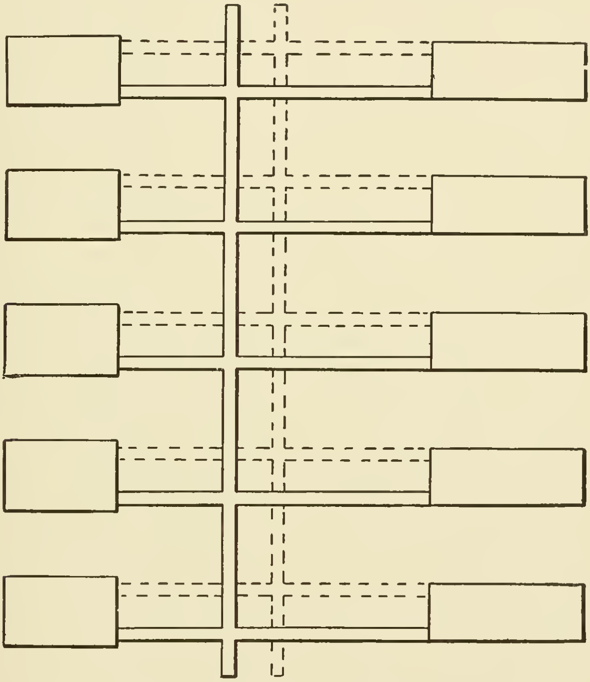


Fig. 4. Duplicate System of Piping

Material. Steel pipe, lap welded and fastened together by means of flanges, is to be recommended for all steam piping. The flanges may be screwed on the ends of sections and calked so as to render this connection steam tight, though in large sizes it is better to have the flanges welded to the pipes. This latter construction costs no more for large pipes and is much more reliable. All valves and fittings are made in two grades or weights, one for low pressures, and the other for high pressures. The high-pressure fittings should always be used for electrical stations. Gate valves should always be selected, and, in large sizes, they should be provided with a by-pass.

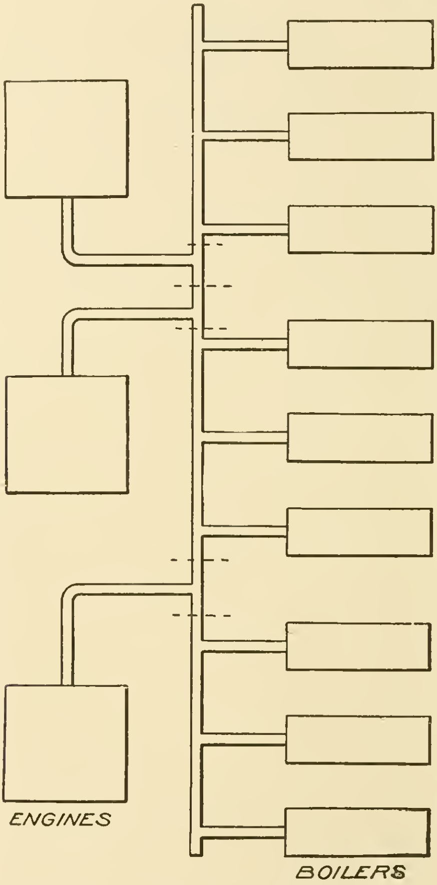
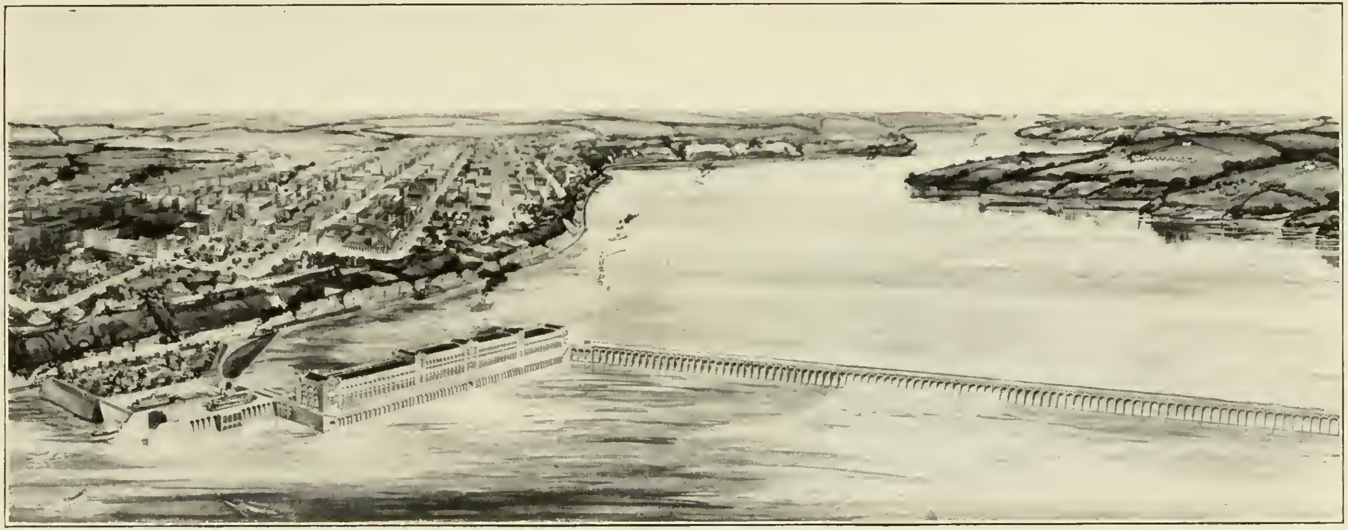


Fig. 5. Arrangement of Boilers and Engines in Very Large Plants

Asbestos, either alone or with copper rings, vulcanized India rubber, asbestos and India rubber, etc., are used for packing between flanges to render them steam tight. Where there is much expansion, the material selected should be one that possesses considerable



BIRDSEYE VIEW OF THE MISSISSIPPI RIVER DAM AND POWER HOUSE AT KEOKUK, IOWA

Boats pass through the forebay at the left and through the lock near the power house to the river below. The dam, which is 4700 feet long, is of concrete construction as well as the power house and the ultimate capacity of the plant is expected to be over 300,000 horsepower. The accomplishment of the project is considered an engineering triumph and indicates what may be expected in years to come in connection with all of our great waterways

Courtesy of Mississippi River Power Company

elasticity. Joints for high-pressure systems require much more care than those for low-pressure systems, and the number of joints should be reduced to a minimum by using long sections of pipe.

Fittings. A list of the various fittings required for steam piping, together with their descriptions, is given in books on boilers. One precaution to be taken is to see that such fittings do not become too numerous or complicated, and it is well not to depend too much on automatic fittings. Steam separators should be large enough to serve as a reservoir of steam for the engine and thus equalize, to a certain extent, the velocity of flow of steam in the pipes.

Expansion. In providing for the expansion of pipes due to change of temperature, **U** bends made of steel pipe and having a radius of curvature not less than six times, and preferably ten times the diameter of the pipe, are preferred. Copper pipes cannot be recommended for high pressures, while slip expansion joints are most undesirable on account of their liability to bind.

Size. The size of steam pipes is determined by the velocity of flow. Probably an average velocity of 60 feet per second would be better than 100 feet per second, though in some cases where space is limited a velocity as high as 150 feet per second has been used.

Loss in Pressure. The loss in pressure in steam pipes may be obtained from the formula

$$p_1 - p_2 = \frac{Q^2 w L}{c^2 d^5}$$

where $p_1 - p_2$ is the loss in pressure in pounds per square inch; Q is the quantity of steam in cubic feet per minute; d is the diameter of pipe in inches; L is the length in feet; w is the weight per cubic feet of steam at pressure p_1 and c is a constant, depending on size of pipe, values of which for the variation in the size of pipe are as follows:

Diameter of pipe	½″	1″	2″	3″	4″	5″	6″	7″	8″	9″	10″
Value of c	36.8	45.3	52.7	56.1	57.8	58.4	59.5	60.1	60.7	61.2	61.8
Diameter of pipe	12″	14″	16″	18″	20″	22″	24″				
Value of c	62.1	62.3	62.6	62.7	62.9	63.2	63.2				

Mounting. In mounting the steam pipe, it should be fastened rigidly at one point, preferably near the center of a long section, and allowed a slight motion longitudinally at all other supports. Such supports may be provided with rollers to allow for this motion, or the pipe may be suspended from wrought-iron rods which will give a flexible support.

Location. Practice differs in the location of the steam piping, some engineers recommending that it be placed underneath the engine-room floor and others that it be located high above the engine-room floor. In any case it should be made easily accessible, and the valves should be located so that nothing will interfere with their operation. Proper provision must be made for draining the pipes.

Lagging. All piping as well as joints should be carefully covered with a good quality of lagging as the amount of steam condensed in a bare pipe, especially if of any great length, is considerable. In selecting a lagging bear in mind that the covering for steam pipes should be incombustible, should present a smooth surface, should not be damaged easily by vibration or steam, and should have as large a resistance to the passage of heat as possible. It must not be too thick, otherwise the increased radiating surface will counterbalance the resistance to the passage of heat.

The loss of power in steam pipes due to radiation is

$$H = .262\, r\, L\, d$$

where H is loss of power in heat units; d is diameter of pipe in inches; L is the length of pipe in feet; and r is a constant depending on steam pressure and pipe covering, values of which for the variations of these two factors are as follows:

Steam pressure in pounds (absolute)......	40	65	90	115
Values of r for uncovered pipe............	437	555	620	684
Value of r for pipe covered with 2 inches of hair felt..........................	48	58	66	73

Referring to tables in books on boilers, the relative values of different materials used for covering steam pipes may be found.

Superheated Steam. Superheated steam reduces condensation in the engines as well as in the piping, and increases the efficiency of the system. Its use was abandoned for several years, due to difficulties in lubricating and packing the engine cylinders, but by the use of mineral oils and metallic packing, these difficulties have been done away with to a large extent, while steam turbines are especially adapted to the use of superheated steam. The application of heat directly to steam, as is done in the superheater, increases the

TABLE IV

Boiler Efficiencies

Amount of Superheat	Water Evaporated per Pound of Coal	
	Without Superheat	With Superheat
40 degrees F.	7.82	9.99
42 degrees F.	6.42	7.06
55 degrees F.	6.00	7.00
56.5 degrees F.	6.78	8.66
55.2 degrees F.	7.15	8.65

efficiency of the boilers. Table IV shows the increase in boiler efficiency for a certain boiler test, the results being given in pounds of water changed to dry, saturated steam. Tests on various engines show a gain in efficiency as high as 9 per cent with a superheat of 80° to 100° F., while special tests in some cases show even a greater gain.

Superheaters are very simple, consisting of tubular boilers containing steam instead of water, and either located so as to utilize the heat of the gases, the same as economizers, or separately fired. They should be arranged so that they may be readily cut out of service, if necessary, and provision must be made for either flooding them or turning the hot gases into a by-pass, as the tubes would be injured by the heat if they contained neither water nor steam. Superheaters may be mounted in the furnace of the regular boiler setting or they may have furnaces of their own and be separately fired. For electrical stations using superheated steam the former type is usually employed and it has proved very satisfactory for moderate degrees of superheat.

Feed Water. All water available for the feeding of boilers contain some impurities, among the most important of which as regards boilers are soluble salts of calcium and magnesium. Bicarbonates of the alkaline earths cause precipitations on the interior of boilers, forming *scale.* Sulphate of lime is also deposited by concentration under pressure. Scale, when formed, not only decreases the efficiency of the boiler but also causes deterioration, for if sufficiently thick, the diminished conducting power of the boiler allows the tubes or plates to be overheated and to crack or burst. Again, the scale may keep the water from contact with sections of the heated plates for some time and then, giving way, large volumes of steam are generated very quickly, and an explosion may result.

Some processes to prevent the formation of scale are used, which affect the water after it enters the boilers, but they are not to be recommended, and any treatment the water receives should affect it previous to its being fed to the boilers. Carbonates and a small quantity of sulphate of lime may be removed by heating in a separate vessel. Large quantities of sulphate of lime must be precipitated chemically.

Sediment must be removed by allowing the water to settle. Vegetable matters are sometimes present, which cause a film to be deposited. Certain gases, in solution—such as oxygen, nitrogen, etc.—cause pitting of the boiler. This effect is neutralized by the addition of chemicals. Oil from the engine cylinder is particularly destructive to boilers and when present in the condensed steam must be carefully removed.

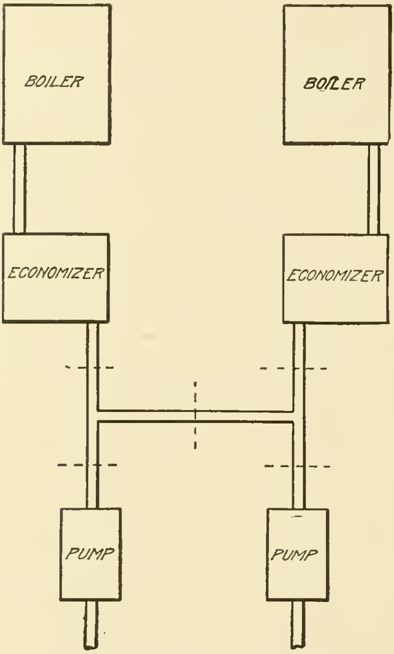


Fig. 6. Feeding System for Boilers and Pumps

Feeding Appliances. Both feed pumps and injectors are used for feeding the water to the boilers. *Feed pumps* may be either steam- or motor-driven. Steam-driven pumps are very inefficient, but they are simple and the speed is easily controlled. Motor-driven pumps are more efficient and neater, but more expensive and more difficult to regulate efficiently over a wide range of speed. Direct-acting pumps may have feed-water heaters attached to them, thus increasing the efficiency of the apparatus as a whole. The supply of electrical energy must be constant if motor-driven pumps are to be used.

TABLE V

Rate of Flow of Water, in Feet per Minute, Through Pipes of Various Sizes, for Varying Quantities of Flow

Gallons per Min.	¾ in.	1 in.	1¼ in.	1½ in.	2 in.	2½ in.	3 in.	4 in.
5	218	122½	78½	54½	30½	19½	13½	7⅔
10	436	245	157	109	61	38	27	15⅓
15	653	367½	235½	163½	91½	58½	40½	23
20	872	490	314	218	122	78	54	30⅔
25	1090	612½	392½	272½	152½	97½	67½	38⅓
30		735	451	327	183	117	81	46
35		857½	549½	381½	213½	136½	94½	53⅔
40		980	628	436	244	156	108	61⅓
45		1102½	706½	490½	274½	175½	121½	69
50			785	545	305	195	135	76⅔
75			1177½	817½	457½	292½	202½	115
100				1090	610	380	270	153⅓
125					762½	487½	337½	191⅔
160					915	585	405	230
175					1067½	682½	472½	268⅓
200					1220	780	540	306⅔

Feed pipes must be arranged so as to reduce the risk of failure to a minimum, and for this reason they are almost always duplicated. More than one water supply is also recommended if there is the slightest danger of interruption on this account. One common arrangement of feed-water apparatus is to install a few large pumps supplying either of two mains from which the boiler connections are taken. This is a complicated and costly system of piping. A scheme for feeding two boilers where each pump is capable of supplying both boilers is shown in Fig. 6. Pipes should be ample in cross-section, and, in long lengths, allowance must be made for expansion. Cast iron or cast steel is the material used for their construction; the joints being made by means of flanges fitted with rubber gaskets.

The rate of flow of water in feet per minute through pipes of various sizes is given in Table V. A flow of 10 gallons per minute for each 100 h. p. of boiler equipment should be allowed without causing an excessive velocity of flow in the pipes—400 to 600 feet per minute represents a fair velocity.

Boiler Setting. The economical use of coal depends, to a large extent, on the setting of the boiler and proper dimensions of the furnaces. Internally-fired boilers require support only, while the setting of externally-fired boilers requires provision for the furnaces. Common brick, together with fire brick for the lining of portions exposed to the hot gases, are used almost invariably for boiler settings. It is customary to set the boiler units up in batteries of two, using a 20-inch wall at the sides and a 12-inch wall between the two boilers. The instructions for settings furnished by the manufacturers should be carefully followed out as they are based on conditions which give the best results in the operation of their boilers.

Draft. The best ratio of heating to grate surface for boiler plants depends upon the kind of fuel used and the draft employed. Based on a draft of 0.5 inch of water, the following values are given for different grades of fuel:

Pocahontas, W. Va., 45; Youghiogheny, Pa., 48; Hocking Valley, O., 45; Big Muddy, Ill., 50; Lackawanna, Pa., No. 1 buckwheat, 32. The first of these coals is semi-bituminous, the Lackawanna coal is anthracite, and the other coals are bituminous.

Natural Draft. Natural draft is the most commonly used and is the most satisfactory under ordinary circumstances. In determining the size of the chimney necessary to furnish this draft, the following formula is given by Kent:

$$A = \frac{.06\,F}{\sqrt{h}} \qquad \text{or } h = \left(\frac{.06\,F}{A}\right)^2$$

where A = area of chimney in sq. ft.; h = height of chimney in ft.; and F = pounds of coal per hour.

The height of chimney should be assumed and the area calculated, remembering that it is better to have the chimney too large than too small.

The chimney may be either of brick or iron, the latter having a less first cost but requiring repairs at frequent intervals. General rules for the design of a brick chimney may be given as follows:

The external diameter of the base should not be less than $\frac{1}{10}$ of the height.
Foundations must be of the best.
Interiors should be of uniform section and lined with fire brick.
An air space must exist between the lining and the chimney proper.

The exterior should have a taper of from $\frac{1}{16}$ to $\frac{1}{4}$ inch to the foot. Flues should be arranged symmetrically.

Fig. 7 shows the construction of a brick chimney of good design, this chimney being used with boilers furnishing engines which develop 14,000 h. p.

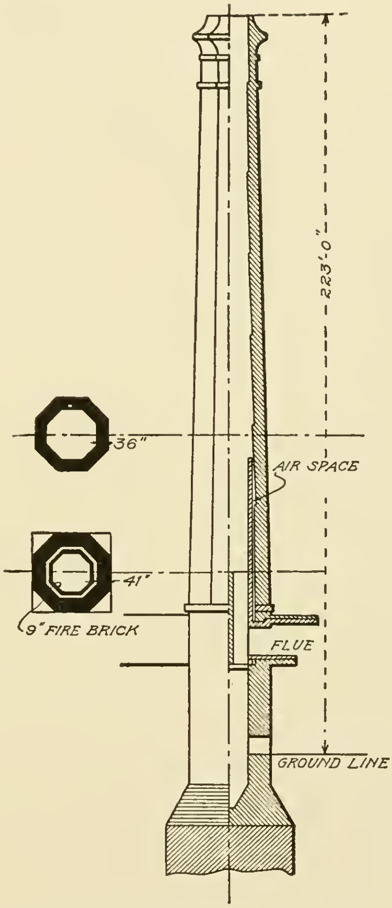


Fig. 7. Good Design of Brick Chimney

Mechanical Draft. Mechanical draft is a term which may be used to embrace both forced and induced draft. The first cost of mechanical-draft systems is less than that of a chimney, but the operation and repair are much more expensive and there is always the risk of break-down. Artificial draft has the advantage that it can be varied within large limits and it can be increased to any desired extent, thus allowing the use of low grades of coal.

Firing of Boilers. Coal is used for fuel to a greater extent than any other material, though oil, gas, wood, etc., are used in some localities. Local conditions, such as availability, cost, etc., should determine the material to be used; no general rules can be given. From data regarding the relative heating values of different fuels we find: that 1 pound of petroleum, about $\frac{1}{7}$ of a gallon, is equivalent, when used with boilers, to 1.8 pounds of coal and there is less deterioration of the furnace with oil; that $7\frac{1}{2}$ to 12 cubic feet of natural gas are required as the equivalent of 1 pound of coal, depending on the quality of the gas; that $2\frac{1}{2}$ pounds of dry wood is assumed as the equivalent of 1 pound of coal.

Stoking. When coal is used, it requires stoking and this may be accomplished either by hand or by means of mechanical stokers, many forms of which are available. Mechanical stoking has the advantage over hand stoking in that the fuel may be fed to the furnace more uniformly, thus avoiding the subjection of the fires and boilers to sudden blasts of cold air as is the case when the fire doors are opened; in that a poorer grade of coal may be burned, if necessary; and in that the trouble due to smoke is much reduced. It may be said that mechanical stokers are used almost universally in the more important electrical plants. Economic use of fuel requires great care in firing, especially if it is done by hand.

Where gas is used, the firing may be made nearly automatic, and the same is true of oil firing, though the latter requires more complicated burners, as it is necessary that the oil be vaporized.

In large stations, operated continuously, it is desirable that, as far as possible, all coal and ashes be handled by machinery, though the difference in cost of operation should be carefully considered before installing extensive coal-handling machinery. Machinery for automatically handling the coal will cost from $7.50 to $10 per horse-power rating of boilers for installation, while the ash-handling machinery will cost from $1.50 to $3 per horse-power.

The coal-handling devices usually consist of chain-operated conveyors which hoist the coal from railway cars, barges, etc., to overhead bins from which it may be fed to the stokers. The ashes may be handled in a similar manner, by means of scraper conveyors, or small cars may be used. Either steam or electricity may be used for driving this auxiliary apparatus.

It is always desirable that there be generous provision for the storage of fuel sufficient to maintain operations of the plant over a temporary failure of supply.

STEAM ENGINES

The choice of steam prime movers is one which is governed by a number of conditions which can be treated but briefly here. The first of these conditions relates to the speed of the engine to be used. There is considerable difference of opinion in regard to this as both high- and low-speed plants are in operation and are giving good satisfaction. Slow-speed engines have a higher first cost and a higher economy. Probably in sizes up to 250 kw., the generator should be driven by high-speed engines; from 250 to 500 kw., the selection of either type will give satisfaction; above 500 indicated horse-power, the slow-speed type is to be recommended. Drop valves cannot be used with satisfaction for speeds above about 100 revolutions per minute, hence high-speed engines must use direct-driven valve gears, usually governed by shaft governors. Corliss valves are used on nearly all slow-speed engines.

The steam pressure used should be at least 125 pounds per square inch at the throttle and a pressure as high as 150 to 160 pounds is to be preferred.

Close regulation and uniform angular velocity are required for driving generators, especially alternators which are to operate in parallel. This means sensitive and active governors, carefully designed flywheels, and proper arrangement of cranks when more than one is used.

High-speed engines should not have a speed change greater than $1\frac{1}{2}$ per cent from no load to full load, but for prime movers used for driving large alternators operated in multiple, a speed change as great as 4 or 5 per cent may be desirable. The variation in angular velocity, where alternators are to be operated in parallel, should be within such limits that at no time will the rotating part be more than $\frac{1}{60}$ of the pitch angle of two poles from the position it would occupy if the angular velocity were uniform at its mean value.

For large engine-driven plants or plants of moderate size, compound condensing engines are almost universally installed. The advantage of these engines in increased economy are in part counterbalanced by higher first cost and increased complications, together with the pumps and added water supply necessary for the condensers. The approximate saving in amount of steam is shown in Table VI, which applies to a 500 horse-power unit.

Triple expansion engines are seldom used for driving electrical machinery, as their advantages under variable loads are doubtful. Compound engines may be tandem or cross-compound and either horizontal or vertical. The use of cross-compound engines tends to produce uniform angular velocity, but the cylinder should be so proportioned that the amount of work done by each is nearly equal.

TABLE VI

Engine	Pounds of Steam per H. P. Hour
Simple non-condensing	30
Simple condensing	22
Compound non-condensing	24
Compound condensing	16

A cylinder ratio of about 3½ to 1 will approximate average conditions. Either vertical or horizontal engines may be installed, each having its own peculiar advantages. Vertical engines require less floor space, while horizontal engines have a better arrangement of parts. Either type should be constructed with heavy parts and erected on solid foundations.

Engines should preferably be direct-connected, but this is not always feasible, and gearing, belt, or rope drives must be resorted to. Countershafts, belt or rope driven, arranged with pulleys and belts for the different generators, and with suitable clutches, are largely used in small stations. They consume considerable power and the bearings require attention.

Careful attention must be given to the lubrication of all running parts, and extensive oil systems are necessary in large plants. In such systems a continuous circulation of oil over the bearings and through the engine cylinders is maintained by means of oil pumps. After passing through the bearings, the machine oil goes to a properly arranged oil filter where it is cleaned and then pumped to the bearings again. A similar process is used in cylinder lubrication, the oil being collected from the exhaust steam, and only enough new oil is added to make up for the slight amount lost. The latter system is not installed as frequently as the continuous system for bearings.

STEAM TURBINES

Advantages. The steam turbine is now very extensively used as a prime mover for generators in power stations on account of its many advantages, some of which may be stated as follows:

1. High steam economy at all loads.
2. High steam economy with rapidly fluctuating loads.

3. Small floor space per kw. capacity, reducing to a minimum the cost of real estate and buildings.
4. Uniform angular velocity, thus facilitating the parallel operation of alternators.
5. Simplicity in operation and low expense for attendance.
6. Freedom from vibration, hence low cost for foundations.
7. Steam economy is not appreciably impaired by wear or lack of adjustment in long service.
8. Adaptability to high steam pressures and high superheat without difficulty in operation and with consequent improvement in economy.
9. Condensed steam is kept entirely free from oil and can be returned to the boilers without passing through an oil separator.

Types. The detailed descriptions of the different types of steam turbines are given in books devoted to steam engines and turbines and only a small amount of space can be devoted to them here. The first classification of steam turbines is into the impulse type and the reaction type of turbine. In the impulse type the steam is expanded in passing through suitable nozzles and does useful work in moving the blades of the rotating part by virtue of its kinetic energy. In the reaction type the steam is only partially expanded before it comes into contact with the blades and much of the work on the moving blades is accomplished by the further expansion of the steam and the reaction of the steam as it leaves the blades. Of the impulse type the *DeLaval* and the *Curtis* turbines are well-known makes. The DeLaval turbine is built in small and moderate sizes only and is of the single-stage type. The Curtis turbine is built in all sizes up to the very largest and is of the multi-stage type. The Curtis turbine may be briefly described as follows:

The Curtis turbine is divided into sections or stages, each stage containing one or more sets of stationary vanes and revolving buckets. These vanes and buckets are supplied with steam which passes through suitable nozzles to give it the proper expansion and velocity as it issues from the nozzles. By dividing the work into stages, the nozzle velocity of the steam is kept down to a moderate value in each stage and the energy of the steam is effectively given up to the rotating part without excessively high speeds. Fig. 8

shows the arrangement of nozzles, buckets, and stationary blades or guiding vanes for two stages. A complete turbine of the vertical type and of 5,000 kw. capacity is shown in Fig. 9. Governing is accomplished by automatically opening or closing some of the nozzles,

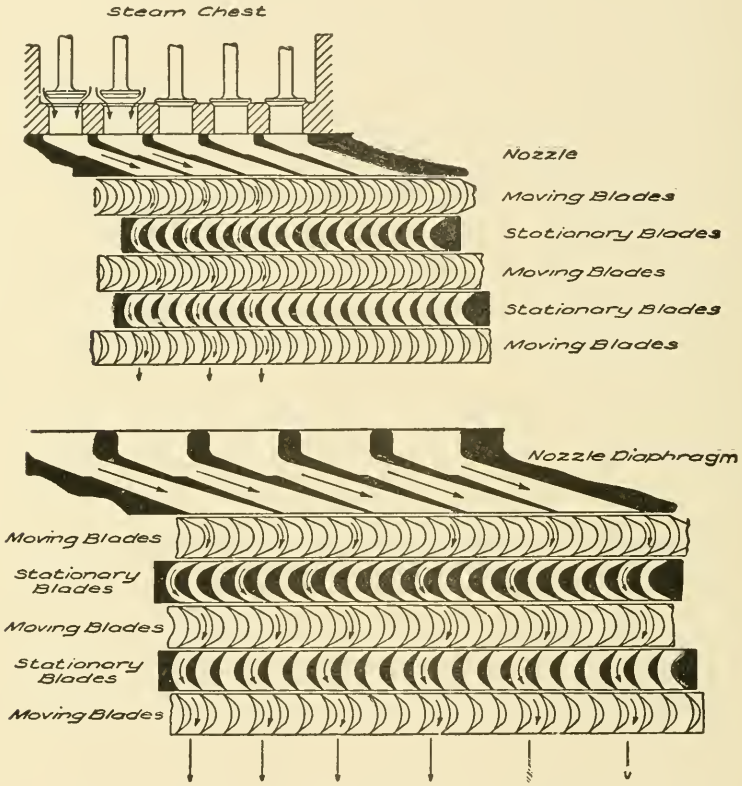


Fig. 8. Diagram of Nozzles and Buckets in Curtis Steam Turbine

and on overloads the steam may be automatically led directly into the second stage of the turbine. The step bearing which supports the weight of the rotating part may be lubricated by either oil or water under high pressure, this pressure being made great enough to support the weight of the moving element on a thin film of the lubricant. Only a vertical type of the Curtis turbine is shown here but it is also manufactured in the horizontal form.

Of the reaction turbines the *Parson's* type is the most prominent one. It is manufactured in the United States by the Westinghouse Machine Company and the Allis-Chalmers Company. An elementary drawing of the cross-section of the Allis-Chalmers turbine is shown in Fig. 10. Steam enters this turbine at *C* through the governing valve *D*, passes through the opening *E*, and thence expands in its passages through the series of revolving and stationary blades in the three stages *H*, *J*, and *K*. The steam pressure is balanced by means of a series of disks or balance pistons shown at *L*, *M*, and *N*. The valve shown at *V* is automatically opened on overload, thus admitting steam directly into stage *J*.

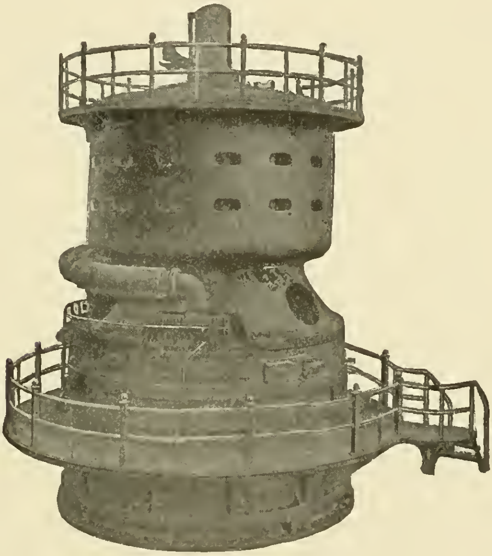


Fig. 9. Turbo-Alternator of 5,000 kw. Capacity

The steam economy of the turbine increases with increase in vacuum approximately as follows: For every increase in vacuum of one inch between 23 inches and 28 inches the increase in economy is 3 per cent for 100-kw. units, 4 per cent for 400-kw. units, and 5 per cent for 1,000-kw. units. This is a greater improvement than can be obtained with steam engines under corresponding conditions

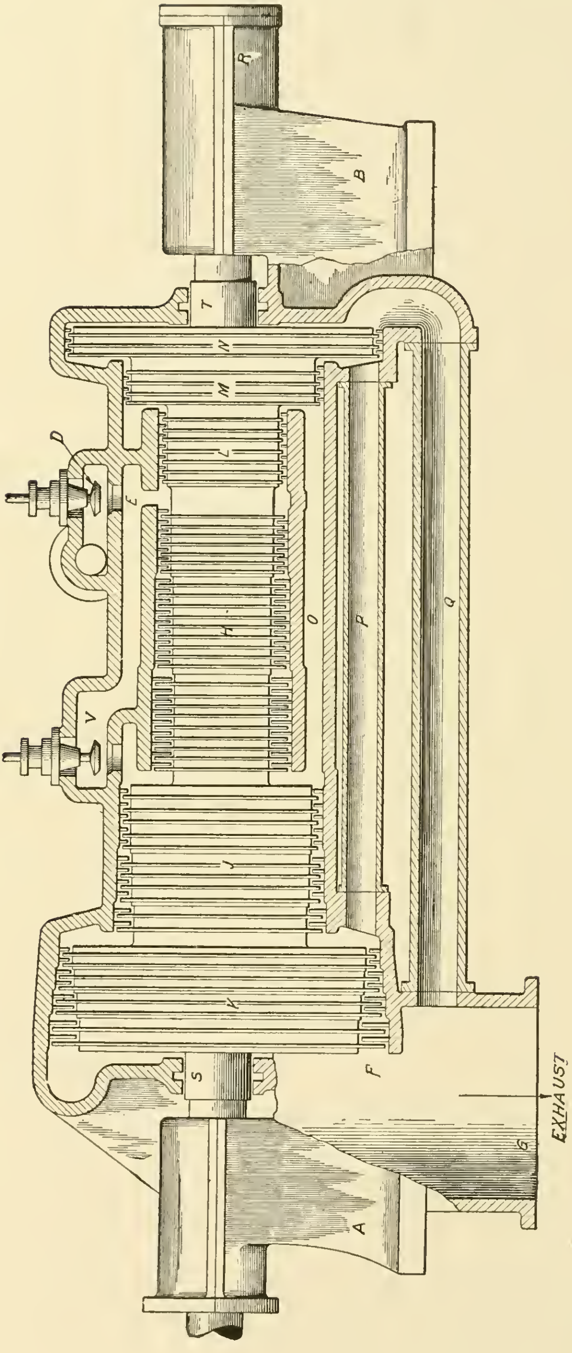


Fig. 10. Parson-Allis-Chalmers Turbine

and the exhaust-steam or low-pressure turbine is being introduced to work in conjunction with the reciprocating steam engine, the steam expanding down to about atmospheric pressure in the engine and continuing down to a high vacuum through the low-pressure turbine. A receiver may be introduced between the engine and the turbine. A higher steam economy is claimed for such a combination than could be secured by either engine or turbine alone.

HYDRAULIC PLANTS

Because of the relative ease with which electrical energy may be transmitted long distances, it has become quite common to locate large power stations where there is abundant water power, and to transmit the energy thus generated to localities where it is needed. This type of plant has been developed to the greatest extent in the western part of the United States, where in some cases the transmission lines are very extensive. The power houses now completed, or in the course of erection at Niagara Falls, are examples of the enormous size such stations may assume.

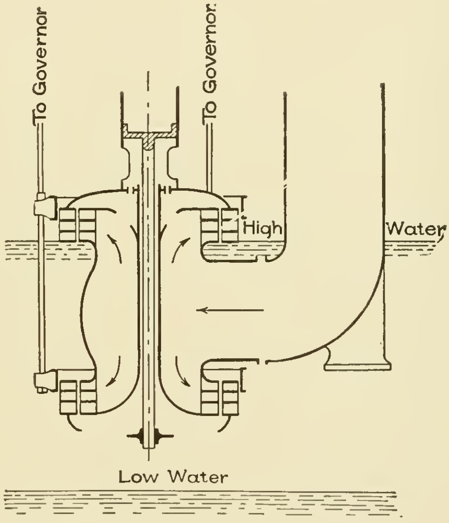


Fig. 11. Diagram of Reaction Turbines

Before deciding to utilize water power for driving the machinery in central stations, the following points should be noted:

1. The amount of water power available.
2. The possible demand for power.
3. Cost of developing this power as compared with cost of plants using other sources of power.
4. Cost of operation compared with other plants and extent of transmission lines.

Hydraulic plants are often much more expensive than steam plants, but the first cost is more than made up by the saving in operating expenses.

Methods for the development of water powers vary with the nature and the amount of the water supply, and they may be studied best by considering plants which are in successful operation, each one of which has been a special problem in itself. A full description of such plants would be too extensive to be incorporated here, but they can be found in the various technical journals.

Water Turbines. Water turbines used for driving generators are of two general classes, *reaction* turbines and *impulse* turbines.

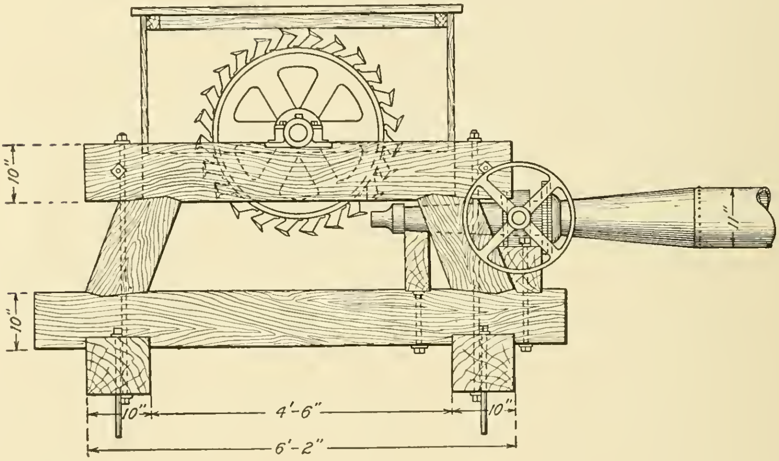
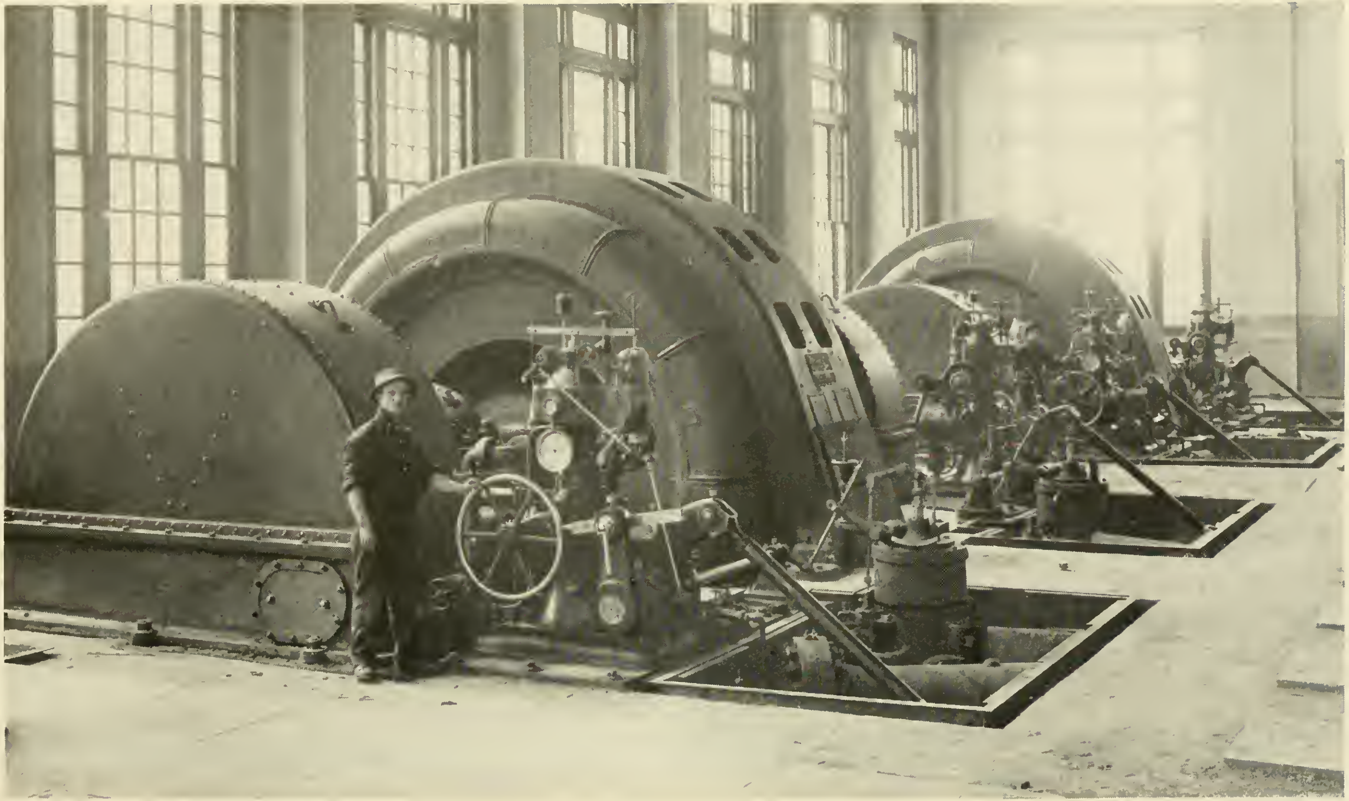


Fig. 12. Pelton Type of Impulse Turbine

Reaction turbines may be subdivided into *parallel-flow, outward-flow,* and *inward-flow* types. Parallel-flow turbines are suited for low falls, not exceeding 30 feet. Their efficiency is from 70 to 72 per cent. Outward-flow and inward-flow turbines give an efficiency from 79 to 88 per cent. Impulse turbines are suitable for very high falls and should be used from heads exceeding, say, 100 feet, though it is difficult to say at what head the reaction turbine would give place to the impulse wheel, as reaction turbines are giving good satisfaction on heads in the neighborhood of 200 feet, while impulse wheels are operated with falls of but 80 feet. A reaction wheel is shown in Fig. 11, and the Pelton wheel, one of the best known types



GENERATING UNITS OF BIG CREEK DEVELOPMENT OF THE PACIFIC LIGHT AND POWER CORPORATION

The main units are of the two-runner type, the wheel disks being pressed onto the projecting overhung ends of the generator shaft. The turbines are the largest impulse units ever constructed and operate under one of the highest heads in the world. Capacity of each generator, 11,000 K. W.

Stone & Webster Construction Company, Construction Engineers

TABLE VII

Pressure of Water

Feet Head	Pressure Pounds per Sq. In.	Feet Head	Pressure Pounds per Sq. In.	Feet Head	Pressure Pounds per Sq. In.	Feet Head	Pressure Pounds per Sq. In.
10	4.33	105	45.48	200	86.63	295	127.78
15	6.49	110	47.64	205	88.80	300	129.95
20	8.66	115	49.81	210	90.96	310	134.28
25	10.82	120	51.98	215	93.13	320	138.62
30	12.99	125	54.15	220	95.30	330	142.95
35	15.16	130	56.31	225	97.46	340	147.28
40	17.32	135	58.48	230	99.63	350	151.61
45	19.49	140	60.64	235	101.79	360	155.94
50	21.65	145	62.81	240	103.90	370	160.27
55	23.82	150	64.97	245	106.13	380	164.61
60	25.99	155	67.14	250	108.29	390	168.94
65	28.15	160	69.31	255	110.46	400	173.27
70	30.32	165	71.47	260	112.62	500	216.58
75	32.48	170	73.64	265	114.79	600	259.90
80	34.65	175	75.80	270	116.96	700	303.22
85	36.82	180	77.97	275	119.12	800	346.54
90	38.98	185	80.14	280	121.29	900	389.86
95	41.15	190	82.30	285	123.45	1000	433.18
100	43.31	195	84.47	290	125.62		

of impulse wheels, is shown in Fig. 12. An efficiency as high as 86 per cent is claimed for the impulse wheel under favorable conditions. The fore bay leading to the flume should be made of such size that the velocity of water does not exceed 1½ feet per second; and it should be free from abrupt turns. The same applies to the tailrace. The velocity of water in wooden flumes should not exceed 7 to 8 feet per second. Riveted steel pipe is used for the penstocks and for carrying water from considerable distances under high heads. In some locations it is buried, in others it is simply placed on the ground. Wooden-stave pipe is used to a large extent when the heads do not much exceed 200 feet. In Table VII is given the pressure of water in pounds per square inch at different heads, while in Table VIII is given considerable data relating to riveted-steel hydraulic pipe. Governors of the usual types are required to keep the speed of the turbine constant under change of load and change of head.

TABLE VIII

Riveted Hydraulic Pipe

Diam. of Pipe in Inches	Area of Pipe in Square Inches	Thickness of Iron by Wire Gauge	Head in Feet the Pipe will Safely Stand	Cu. Ft. Water Pipe will Convey per Min. at Vel. 3 Ft. per Sec.	Weight per Lineal Foot in Pounds
3	7	18	400	9	2
4	12	18	350	16	2¼
4	12	16	525	16	3
5	20	18	325	25	3½
5	20	16	500	25	4¼
5	20	14	675	25	5
6	28	18	296	36	4¼
6	28	16	487	36	5¾
6	28	14	743	36	7½
7	38	18	254	50	5¼
7	38	16	419	50	6¾
7	38	14	640	50	8½
8	50	16	367	63	7½
8	50	14	560	63	9½
8	50	12	854	63	13
9	63	16	327	80	8½
9	63	14	499	80	10¾
9	63	12	761	80	14¼
10	78	16	295	100	9¼
10	78	14	450	100	11¾
10	78	12	687	100	15¾
10	78	11	754	100	17½
10	78	10	900	100	19½
11	95	16	269	120	9¾
11	95	14	412	120	13
11	95	12	626	120	17¼
11	95	11	687	120	18¾
11	95	10	820	120	21
12	113	16	246	142	11¼
12	113	14	377	142	14
12	113	12	574	142	18½
12	113	11	630	142	19¾
12	113	10	753	142	22¾
13	132	16	228	170	12
13	132	14	348	170	15
13	132	12	530	170	20
13	132	11	583	170	22
13	132	10	696	170	24½
14	153	16	211	200	13
14	153	14	324	200	16
14	153	12	494	200	21½
14	153	11	543	200	23½
14	153	10	648	200	26
15	176	16	197	225	13¾
15	176	14	302	225	17
15	176	12	460	225	23
15	176	11	507	225	24½
15	176	10	606	225	28
16	201	16	185	255	14½
16	201	14	283	255	17¼
16	201	12	432	255	24¼
16	201	11	474	255	26½
16	201	10	567	255	29½

Riveted Hydraulic Pipe
(Continued)

Diam. of Pipe in Inches	Area of Pipe in Square Inches	Thickness of Iron by Wire Gauge	Head in Feet the Pipe will Safely Stand	Cu. Ft. Water Pipe will Convey per Min. at Vel. 3 Ft. per Sec.	Weight per Lineal Foot in Pounds
18	254	16	165	320	16½
18	254	14	252	320	20½
18	254	12	385	320	27¼
18	254	11	424	320	30
18	254	10	505	320	34
20	314	16	148	400	18
20	314	14	227	400	22½
20	314	12	346	400	30
20	314	11	380	400	32½
20	314	10	456	400	36½
22	380	16	135	480	20
22	380	14	206	480	24¾
22	380	12	316	480	32¾
22	380	11	347	480	35¾
22	380	10	415	480	40
24	452	14	188	570	27¼
24	452	12	290	570	35½
24	452	11	318	570	39
24	452	10	379	570	43½
24	452	8	466	570	53
26	530	14	175	670	29¼
26	530	12	267	670	38½
26	530	11	294	670	42
26	530	10	352	670	37
26	530	8	432	670	57¼
28	615	14	102	775	31¼
28	615	12	247	775	41¼
28	615	11	273	775	45
28	615	10	327	775	50¼
28	615	8	400	775	61¼
30	706	12	231	890	44
30	706	11	254	890	48
30	706	10	304	890	54
30	706	8	375	890	65
30	706	7	425	890	74
36	1017	11	141	1300	58
36	1017	10	155	1300	67
36	1017	8	192	1300	78
36	1017	7	210	1300	88
40	1256	10	141	1600	71
40	1256	8	174	1600	86
40	1256	7	189	1600	97
40	1256	6	213	1600	108
40	1256	4	250	1600	126
42	1385	10	135	1760	74½
42	1385	8	165	1760	91
42	1385	7	180	1760	102
42	1385	6	210	1760	114
42	1385	4	240	1760	133
42	1385	¼	270	1760	137
42	1385	3	300	1760	145
42	1385	$\frac{5}{16}$	321	1760	177
42	1385	⅜	363	1760	216

TABLE IX

Horse-Power per Cubic Foot of Water per Minute for Different Heads

Heads in Feet	Horse-Power	Heads in Feet	Horse-Power	Heads in Feet	Horse-Power	Heads in Feet	Horse-Power
1	.0016098	170	.273666	330	.531234	490	.788802
20	.032196	180	.289764	340	.547332	500	.804900
30	.048294	190	.305862	350	.563430	520	.837096
40	.064392	200	.321960	360	.579528	540	.869292
50	.080490	210	.338058	370	.595626	560	.901488
60	.096588	220	.354156	380	.611724	580	.933684
70	.112686	230	.370254	390	.627822	600	.965880
80	.128784	240	.386352	400	.643920	650	1.046370
90	.144892	250	.402450	410	.660018	700	1.126860
100	.160980	260	.418548	420	.676116	750	1.207350
110	.177078	270	.434646	430	.692214	800	1.287840
120	.193176	280	.450744	440	.708312	900	1.448820
130	.209274	290	.466842	450	.724410	1000	1.609800
140	.225372	300	.482940	460	.740508	1100	1.770780
150	.241470	310	.499038	470	.756606		
160	.257568	320	.515136	480	.772704		

GAS PLANT

The gas engine using natural gas, producer gas, blast furnace gas, or even illuminating gas in some instances, is being used to a considerable extent as a prime mover for electric generators. The advantages claimed for the gas engine are:

1. Minimum fuel and heat consumption.
2. Low cost of operation and maintenance.
3. Simplification of equipment and small number of auxiliaries.
4. No heat lost due to radiation when engines are idle.
5. Quick starting.
6. Extensions may be easily made.
7. High pressures are limited to the engine cylinders.

As disadvantages of the gas engine may be mentioned the large floor space required; small overload capacity; and the heavy and expensive foundations necessary.

Fig. 13 shows the efficiency and amount of gas consumed by a 500-h. p. engine, Pittsburg natural gas being used.

The only auxiliaries needed where natural gas is employed are the igniter generators and the air compressors—with a pump for the jacket water in some cases—which may be driven by either a motor or a separate gas engine. The jacket water may be utilized for heating purposes in many plants. Cooling towers may be installed where water is scarce.

Parallel operation of alternators when direct-driven by gas engines has been successful, a spring coupling being used between the engines and the generators in some cases to absorb the variation in angular velocity.

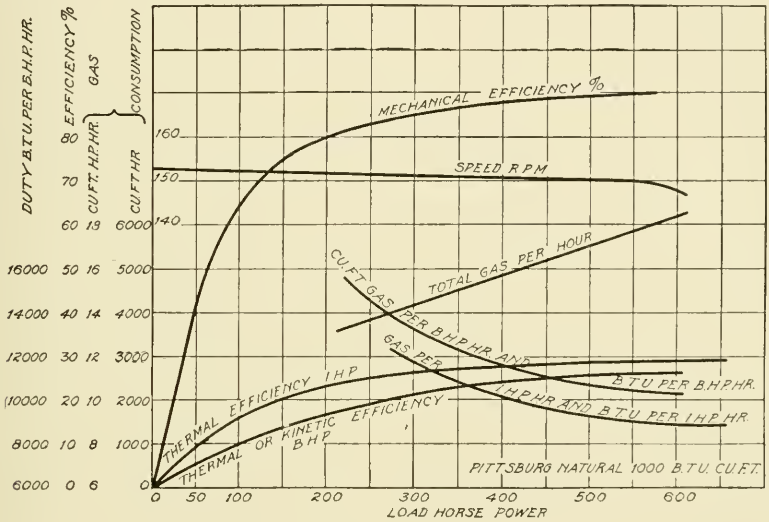


Fig. 13. Efficiency Curves of a 500-H. P. Gas Engine

The overload capacity of gas engines depends upon the manner of rating. The ultimate capacity is reached when the engine is using a full charge of the best mixture of gas and air at each power stroke. Many manufacturers rate their engines at 10 per cent below the maximum capacity, thus allowing for a limited amount of overload. The gas consumption of gas engines is relatively high at loads less than 50 per cent of normal; hence, it is desirable that the load be fairly constant and at some value between 50 and 100 per cent of the rating of the machine. H. G. Stott has proposed that the gas engine be combined with the steam turbine in some electrical plants, since the turbine can carry heavy overloads and is fairly economical on all loads. In such a plant the steam turbine would carry the fluctuations, and arrangements would be made so that the gas engine would carry a nearly constant load.

Gas-producers for gas engines are of two types: the *suction producer,* used for small plants and employing high-grade fuels; and the *pressure producer,* used for the larger units and manufactured for all grades of fuel.

The fact that no losses occur, due to heat radiation when the machines are not running, and the lack of losses in piping, add greatly to the plant efficiency. If producer gas or blast-furnace gas is used, a larger engine must be installed to give the same power than when natural or ordinary coal gas is used. Electric stations are often combined with gas works, and gas engines can be installed in such stations to particular advantage in many cases.

In addition to the gas engine, other forms of internal combustion engines, such as oil engines and gasoline engines, are being used to a limited extent in small stations.

ELECTRIC PLANT

GENERATORS

The first thing to be considered in the electric plant is the generators, after which the auxiliary apparatus in the way of exciters, controlling switches, safety devices, etc., will be taken up. A general rule which, by the way, applies to almost all machinery for power stations, is to select apparatus which is considered as "standard" by the manufacturing companies. This rule should be followed for two reasons: *First,* reliable companies employ men who may be considered as experts in the design of their machines, and their best designs are the ones which are standardized. *Second,* standard apparatus is from 15 to 25 per cent cheaper than semi-standard or special work, owing to larger production, and it can be furnished on much shorter notice. Again, repair parts are more cheaply and readily obtained.

Specifications should call for performance, and details should be left, to a very large extent, to the manufacturers. Following are some of the matters which may be incorporated in the specifications for generators:

1. Type and general characteristics.
2. Capacity and overload with heating limits.
3. Commercial efficiency at various loads.
4. Excitation.
5. Speed and regulation.
6. Mechanical features.

Types. The type of machine will be determined by the system selected. Generators may be direct-current or alternating-current—single or polyphase—or as in some plants now in operation, they may be double-current. The voltage, compounding, frequency, etc., should be stated. Direct-current machines are seldom wound for a voltage above 600, but alternating-current generators may be purchased which will give as high as 15,000 volts at the terminals. As a rule it is well not to use an extremely high voltage for the generators themselves, but to use step-up transformers in case a very high line voltage is necessary. Up to about 7,000 volts, generators may be safely used directly on the line. Above this, local conditions will decide whether to connect the machine directly to the line or to step up the voltage. Machines wound for high potential are more expensive for the same capacity and efficiency, but the cost of step-up transformers and the losses in the same are saved by using such machines, so that there is a slight gain in efficiency which may be utilized in better regulation of the system, or in lighter construction of the line. On the other hand, lightning troubles are liable to be aggravated when transformers are not used, as the transformers act as additional protection to the machines, and if the transformers are injured they may be more readily repaired or replaced.

The following voltages are considered standard: Direct-current generators 125, 250, 550-600. Alternating-current systems, high pressure, 2,200, 6,600, 11,000, 22,000, 33,000, 44,000, 66,000, 88,000, and 110,000. The generators, when used with transformers, should be capable of giving a no-load voltage 10 per cent in excess of these figures. Twenty-five and 60 cycles are considered as standard frequencies, the former being more desirable for railway work and the latter for lighting purposes.

Capacity. The size of machines to be chosen has been briefly considered. Alternators are rated for non-inductive load or a power

TABLE X
Average Maximum Efficiencies

Kw.	Per Cent	Kw.	Per Cent
5	85	150	93
10	88	200	94
25	90	500	95
50	92	1000	96

factor of unity unless a different power factor is distinctly stated. Aside from the overload capacity to be counted upon as reserve, the Standardization Report of the American Institute of Electrical Engineers recommends the following for the heating limits and overload capacity of generators:

Maximum Values of Temperature Elevation

Field and armature, by resistance,	50° C.
Commutator and collector rings and brushes, by thermometer,	55° C.
Bearings and other parts of machine, by thermometer,	40° C.

Overload capacity should be 25 per cent for two hours, with a temperature rise not to exceed 15 degrees above full load values, the machine to be at constant temperature reached under normal load, before the overload is applied. A momentary overload of 50 per cent should be permissible without excessive sparking or injury. Some companies recommend an overload capacity of 50 per cent for two hours when the machines are to be used for railway purposes. The above temperature increases are based upon a room-temperature of 25° C.

Efficiency. As a rule, generators should have a high efficiency over a considerable range of load, although much depends upon the nature of the load. It is always desirable that maximum efficiency be as high as is compatible with economic investment.

Table X gives reasonable efficiencies which may be expected for generating apparatus. In order to arrive at what may be considered the best maximum efficiency to be chosen, the cost of power generation must be known, or estimated, and the fixed charges on capital invested must also be a known quantity. From the cost of power, the saving on each per cent increase in efficiency can be determined, and this should be compared with the charges on the

TABLE XI

Exciters for Single-Phase Alternating-Current Generators

60 Cycles

Alternator Classificaton			Exciter Classification		
Poles	Kw.	Speed	Poles	Kw.	Speed
8	60	900	2	1.5	1,900
8	90	900	2	1.5	1,900
8	120	900	2	1.5	1,900
12	180	600	2	2.5	1,900
16	300	450	2	4.5	1,800

additional investment necessary to secure this increased efficiency. A certain point will be found where the sum of the two will be a minimum.

If a generator is to be run for a considerable time at light loads, one with low "no-load" losses should be chosen. These losses are not rigidly fixed but they vary slightly with change of load. It is the same question of "all-day efficiency" which is treated, in the case of transformers, in "Power Transmission." Under no-load losses may be considered, in shunt-wound generators, friction losses, core losses, and shunt-field losses. I^2R losses in the series field, in the armature, and in the brushes, vary as the square of the load.

Excitation. Dynamos, if for direct current, may be self-excited, shunt-wound, compound-wound, or separately excited. Separate excitation is not recommended for these machines. Alternators require separate excitation, though they may be compounded by using a portion of the armature current when rectified by a commutator. Automatic regulation of voltage is always desirable, hence, the general use of compound-wound machines for direct currents. Many alternators using rectified currents in series fields for keeping the voltage nearly constant are in service in small plants, as well as several of the so-called "compensated" alternators, arranged with special devices which maintain the same compounding with different power factors. The latter machine gives good satisfaction if properly cared for, but an automatic regulator, governed by the generator voltage and current, which acts directly on the exciter field, is taking its place. This regulator, known as the Tirrill regulator, is described under "Power Transmission." The capacity of the exciters must be such that they will furnish sufficient excitation to maintain normal voltage at the terminals of the generators when running at 50 per cent overload. Table XI gives the proper capacity of exciters for the generators listed. On account of the fact that the speed at which the unit runs is an important factor in the excitation required, no general figure can be given.

Exciters may be either direct-connected or belted to the shaft of the machine which they excite, or they may be separately driven. They are usually compound-wound and furnish current at 125 or 250 volts. Separately-driven exciters are preferred for most plants as they furnish a more flexible system, and any drop in the speed of the generator does not affect the exciter voltage. Ample reserve capacity of exciters should be installed, and in some cases storage batteries, used in conjunction with exciters, are recommended in order to insure reliability of service.

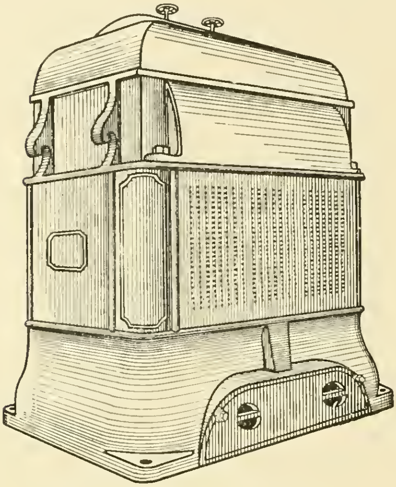


Fig. 14. Air-Cooled Transformer

Speed and Regulation. If direct-connected, the speeds of the generators will be determined by the prime mover selected. If belt-driven, small machines may be run at a high speed, as high-speed machines are cheaper than slow- or moderate-speed generators. In large sizes, this saving is not so great.

When shunt-wound dynamos are used, the inherent regulation should not exceed 2 to 3 per cent for large machines. For alternators, this is much greater and depends on the power factor of the load. A fair value for the regulation of alternators on non-inductive load is 10 per cent.

Mechanical Features. Motor-generator sets, boosters, frequency changers, and other rotating devices come under the head of special apparatus and are governed by the same general rules as generators.

Transformers. Transformers for stepping the voltage from that generated by the machine up to the desired line voltage, or *vice versâ*, at the substation, may be of three general types, according to the method of cooling. Large transformers require artificial means of cooling, if they are not to be too bulky and expensive. They may be air-cooled, oil-cooled, or water-cooled.

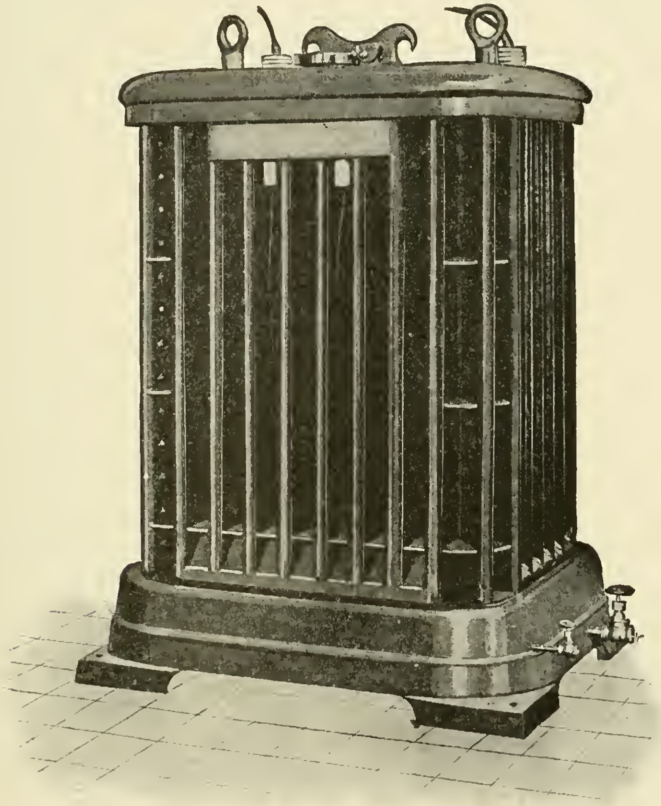


Fig. 15. Oil-Cooled Transformer

Air-cooled transformers, Fig. 14, are usually mounted over an air-tight pit fitted with one or more motor-driven blowers which feed into the pit. The transformer coils are subdivided so that no part of the winding is at a great distance from air and the iron is provided with ducts. Separate dampers control the amount of air which passes between the coils or through the iron. Such transformers give good satisfaction for voltages up to 20,000 or higher, and can be built for any capacity. Care must be taken to see that there is no liability of the air supply failing, as the capacity of the transformers is greatly reduced when not supplied with air.

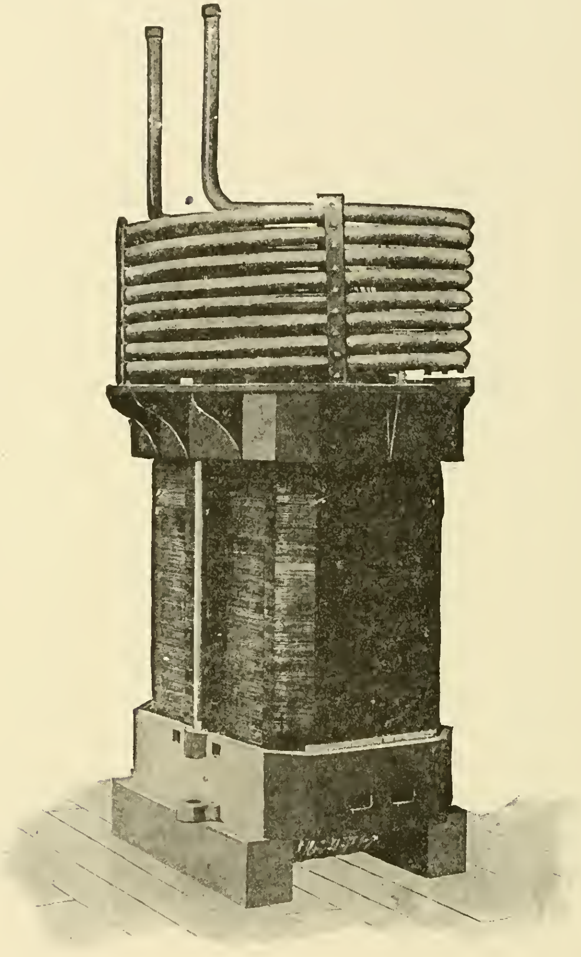


Fig. 16. Water-Cooled Transformer

Oil-cooled transformers, Fig. 15, have their cores and windings placed in a large tank filled with oil. The oil serves to conduct the heat to the case, and the case is usually made either of corrugated sheet metal or of cast iron containing deep grooves, so as to increase the radiating surface. These transformers do not require such heavy insulation on the outside of the coils as air-blast machines because the oil serves this purpose. Simple oil-cooled transformers are seldom built for capacities exceeding 250 kw. as they become too bulky, but they are employed for the highest voltages now in use.

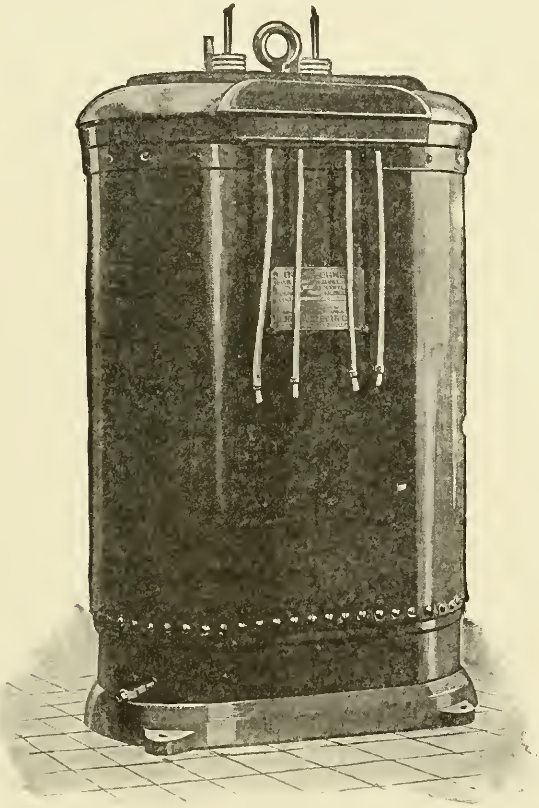


Fig. 17. 400-Kw. Water-Cooled Oil Transformer

Water-cooled transformers, Figs. 16 and 17, are used when high voltages are required. This type is like an oil-cooled transformer, but with water tubes arranged in coils in the top. Cold water passes through these tubes and aids in removing heat from the oil. Some types have the low-tension windings made up of tubes through which the water circulates. Water-cooled transformers must not have the supply of cooling water shut off for any length of time when under normal load or they will overheat.

One or more spare transformers should always be on hand and they should be arranged so that they can be put into service on very short notice.

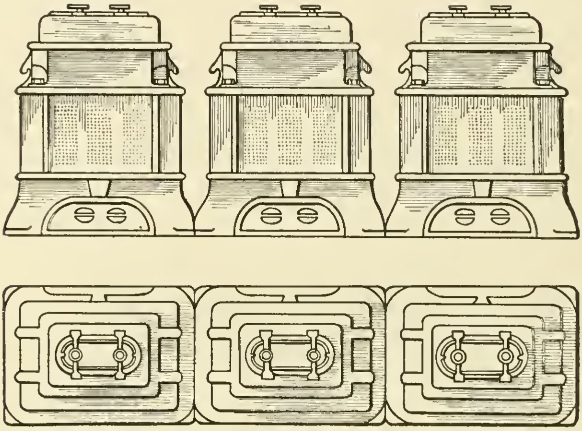


Fig. 18. Three-Phase Air-Blast Transformers. Total Capacity, 3,000 Kw.

Three-phase transformers allow a considerable saving in floor space, as shown by a comparison of the machines in Figs. 18 and 19. They are cheaper than three separate transformers which make up the same capacity, but they are not as flexible as a single-phase transformer and one complete unit must be held for a reserve or "spare" transformer.

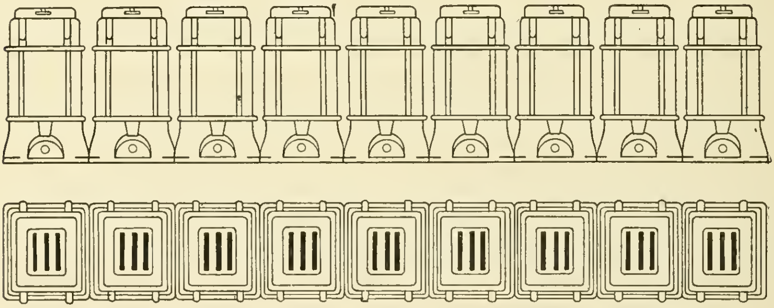


Fig. 19. Single-Phase Air-Blast Transformers. Total Capacity, 3,000 Kw.

Storage Batteries. The use of storage batteries for central stations and substations is clearly outlined in "Storage Batteries."

The chief points of advantage are:

1. Reduction in fuel consumption due to the generating machinery being run at its greatest economy.
2. Better voltage regulation.
3. Increased reserve capacity and less liability to interruption of service.

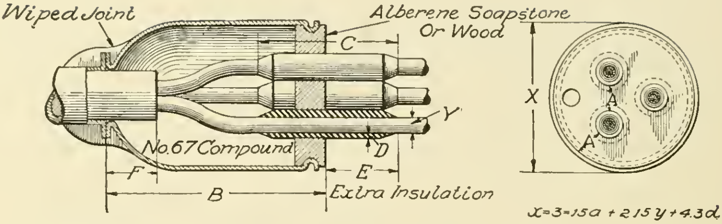
The main disadvantage is the high first cost and depreciation.

SWITCHBOARDS

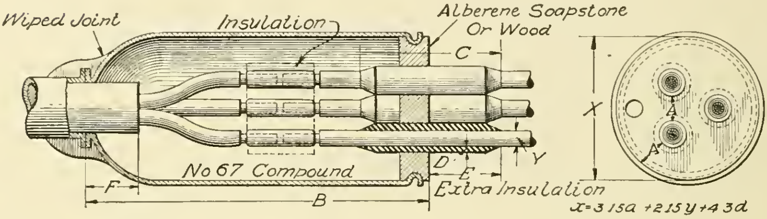
The switchboard is the most vital part of the whole system of supply, and should receive consideration as such. Its objects are: to collect the energy as supplied by the generators and to direct it to the desired feeders, either overhead or underground; to furnish a support for the various measuring instruments connected in service, as well as the safety devices for the protection of the generating apparatus; and to control the pressure of the supply. Some of the essential features of all switchboards are:

1. The apparatus and supports must be fire-proof.
2. The conducting parts must not overheat.
3. Parts must be easily accessible.
4. Live parts except for low potentials must not be placed on the front of the operating panels.
5. The arrangement of circuits must be symmetrical and as simple as it is convenient to make them.
6. Apparatus must be arranged so that it is impossible to make a wrong connection that would lead to serious results.
7. It should be arranged so that extensions may be readily made.

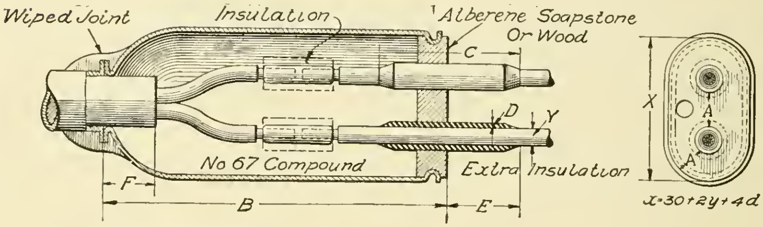
There are two general types—in the first, all of the switching and indicating apparatus is mounted directly on panels; and in the second, the current-carrying parts are at some distance from the panels, the switches being controlled by long connecting rods, or else operated electrically or by means of compressed air. The first may again be divided into direct-current and alternating-current switchboards. It is from the first class of apparatus that the switchboard gets its name and the term is still applied, even when the board proper forms the smallest part of the equipment. The term "switchgear" is now being introduced to cover all of the apparatus connected with the switching operations and the term "switchboard" is being reserved for the panels and their apparatus only. Switchboards have been standardized to the extent that standard generator, exciter, feeder, and motor panels may be purchased for certain classes



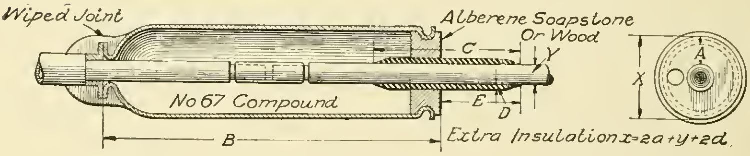
Three-Conductor Cable Without Joints



Three-Conductor Cable With Joints



Two-Conductor Cable With Joints



Single-Conductor Cable With Joints

VOLTS	A	B	C	D	E	F
6,600	1	12	5	$\frac{1}{8}$	$2\frac{1}{2}$	1
13,200	$1\frac{1}{2}$	15	8	$\frac{1}{4}$	4	2
26,400	2	19	14	$\frac{1}{2}$	7	4

$\frac{1}{8}$-inch Lead or $\frac{1}{16}$-inch Brass Bells

Fig. 20. Part Section—Showing Cable Bells in Place

of work, but the vast majority of them are made up as semi-standard or special.

The leads which carry the current from the machines to the switches should be put in with very careful consideration. Their size should be such that they will not heat excessively when carrying the rated overload of the machine, and they should preferably be placed in fire-proof ducts, although low-potential leads do not always require this construction. Curves showing sizes for lead-covered cables for different currents are given in "Power Transmission." Table XII gives standard sizes of wires and cables together with the thickness of insulation necessary for different voltages. Cables should be kept separate as far as possible so that if a fault does occur on one cable, neighboring conductors will not be injured. For lamp and instrument wiring, such as leads to potential and current transformers, the following sizes of wire are recommended:

No. 16 or No. 14, wiring to lamp sockets.
No. 12 wire, $\frac{3}{64}''$ rubber insulation, all other small wiring under 600 volts potential.
No. 12, $\frac{3}{32}''$ rubber insulation for primaries of potential transformers from 600 to 3,500 volts.
No. 8, $\frac{5}{32}''$ rubber insulation for primaries of potential transformers up to 6,600 volts.
No. 8, $\frac{7}{32}''$ rubber insulation for primaries of potential transformers up to 10,000 volts.
No. 4, $\frac{21}{64}''$ rubber insulation for primaries of potential transformers up to 15,000 volts.
No. 4, $\frac{14}{32}''$ rubber insulation for primaries of potential transformers up to 20,000 volts.
No. 4, $\frac{17}{32}''$ rubber insulation for primaries of potential transformers up to 25,000 volts.

Where high-tension cables leave their metallic shields they are liable to puncture, so that the sheath should be flared out at this point and the insulation increased by the addition of compound. Fig. 20 shows such cable bells, as they are called, as are recommended by the General Electric Company. Other types of cable outlets are introduced from time to time. A very excellent type makes use of porcelain sleeve for each conductor at the point when it leaves the lead sheath.

Panels. Central-station switchboards are usually constructed of panels about 90 inches high, from 16 inches to 36 inches wide, and $1\frac{1}{2}$ inches to 2 inches thick. Such panels are made of blue Vermont,

TABLE XII

Standard Wire

(Solid)

AREA	DIAMETER Inches	TERMINAL DRILLING	AMPERES	THICKNESS OF RUBBER INSULATION							GAUGE
				Volts							
Circular Mils	Bare	Drill Number	Constant Current Capacity	600	3,500	6,600	10,000	15,000	20,000	25,000	B. & S.
2,582	.051	30	4								16
4,106	.064	30	6	3/64							14
6,530	.081	30	10	3/64	3/32						12
16,510	.128	18	25	3/64	3/32	5/32	7/32				8
26,251	.162	5	40	1/16							6
41,743	.204	1/4	60	1/16	3/32	5/32	7/32	21/64	14/32	17/32	4
66,373	.257	5/16	90	1/16							2
83,695	.289	11/32	110	5/64							1
105,593	.325	3/8	130	5/64	3/32	5/32	7/32	21/64	14/32	17/32	0
133,079	.365	7/16	170	5/64							00
167,805	.410	15/32	205	5/64							000
211,600	.460	17/32	250	5/64	3/32	5/32	7/32	21/64	14/32	17/32	0000

Standard Cable

(Stranded)

CIRCULAR MILS	DIAMETER, INCHES BARE	TERMINAL DRILLING INCHES	CON. CUR. CAPACITY AMPERES	THICKNESS OF RUBBER INSULATION (For 6000 V. only)
250,000	.568	5/8	290	3/32
300,000	.637	23/32	240	3/32
350,000	.680	3/4	380	3/32
400,000	.735	13/16	420	3/32
500,000	.820	29/32	500	3/32
600,000	.900	1	575	7/64
800,000	1.037	1 1/8	710	7/64
1,000,000	1.157	1 1/4	830	7/64
1,500,000	1.412	1 1/2	1100	1/8
2,000,000	1.65	1 3/4	1350	1/8

pink Tennessee, or white Italian marble, or of black enameled or oiled slate. Slate is not recommended for voltages exceeding 1,100. The panels are made in two or three parts. When made in two parts, the sub-base is from 24 to 28 inches high. They are polished on the front and the edges are beveled. Angle and tee bars or pipe work, together with foot irons and tie rods, form the supports for such panels, and on these panels are mounted the instruments, main switches, or controlling apparatus for the main switches, as the case may be, together with relays and hand wheels for rheostats and regulators.

The usual arrangement of the panels is to have a separate panel for each generator, exciter, and feeder, together with what is known as a station or total-output panel. In order to facilitate extensions and simplify connections, the feeder panels are located at one end of the board, the generator panels are placed at the other end, and the total-output panel occupies a position between the two. The main bus bars extend throughout the length of the generator and feeder panels, and the desired connections are readily made. The instruments required are very numerous. Lists of meters required for standard practice and regular panels are given later.

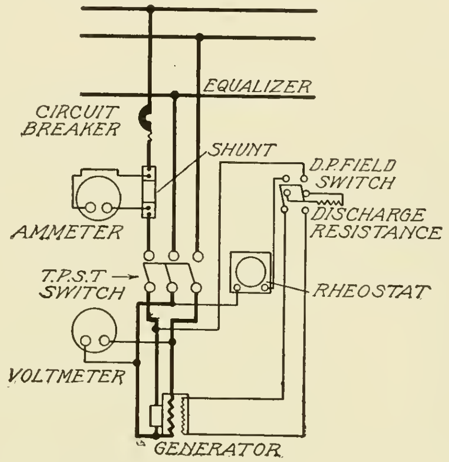


Fig. 21. Wiring Diagram of D. C. Generator Panel

For *direct-current generator panels* or for the *direct-current side of synchronous converters, two-wire system,* there are usually required:

1 Main switch
1 Field switch
1 Ammeter
1 Voltmeter
1 Field rheostat with controlling mechanism
1 Circuit breaker
1 4-point starting switch (for use when machine is to be started as a direct-current motor).
Bus bars and various connections.

These may be arranged in any suitable order, the circuit breaker being preferably located at the top so that any arcing which may occur will not injure other instruments. Fig. 21 gives a wiring diagram of such a panel.

The main switch may be a single- or a double-throw, depending on whether one or two sets of bus bars are used. It may be a triple-pole, as shown in Fig. 21, in which the middle bar serves as the equalizing switch, or the equalizing switch may be mounted on a pedestal near the machine, in which case the generator switch would be double-pole.

The field switch for large machines should be double-pole fitted with carbon breaks and arranged with a discharge resistance consisting of a resistance which is thrown across the terminals of the field just before the main circuit is opened. One voltmeter located on a swinging bracket at the end of the panel, and arranged so that it can be thrown across any machine or across the bus bars by means of a dial switch, is sometimes used, but it is preferable to have a separate meter for each generator.

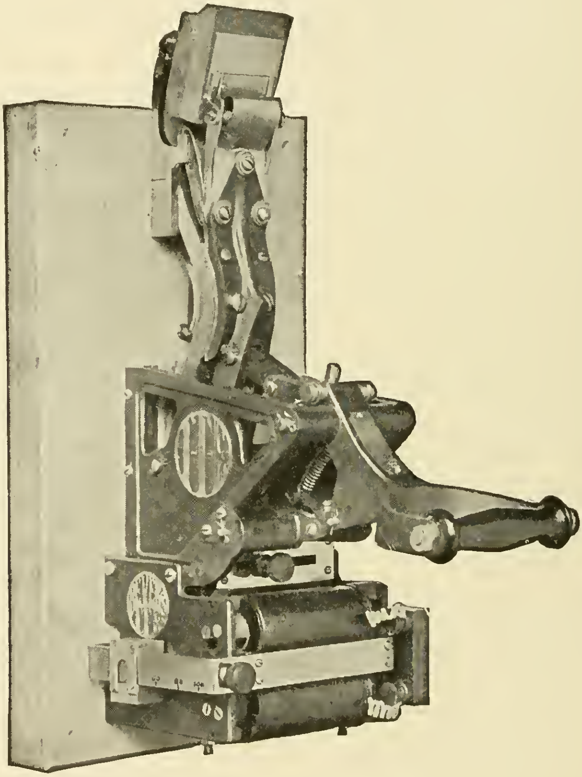


Fig. 22. Carbon Break Circuit Breaker

Small rheostats are mounted on the back of the panel, but large ones are chain-operated and preferably located below the floor, the controlling hand wheel being mounted on the panel.

The circuit breaker may be of the carbon break or the magnetic blow-out type. Figs. 22 and 23 show circuit breakers of these types. Lighting panels for low potentials are often fitted with fuses instead of circuit breakers, in which case they may be open fuses on the back of the panel or enclosed fuses on either the front or back of the panel.

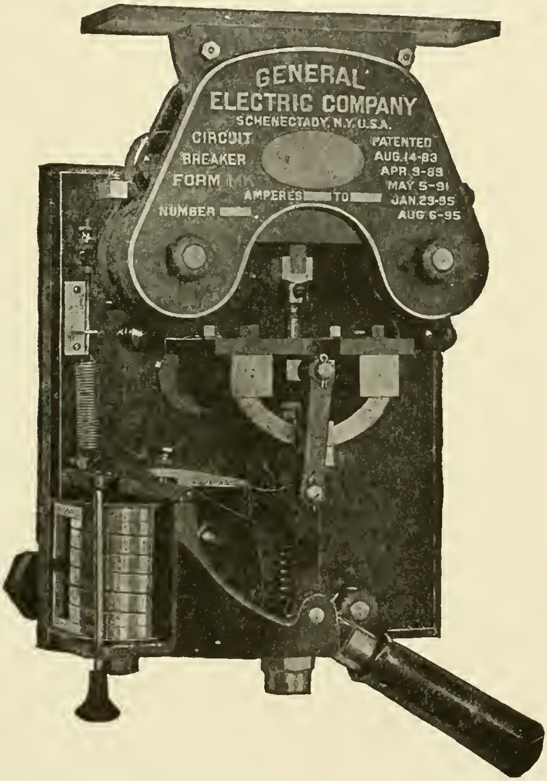


Fig. 23. Magnetic Blow-Out Circuit Breaker

A panel for a *direct-current generator or a synchronous converter for a 3-wire system* should contain:

2 Ammeters.
2 Circuit breakers. Fuses used on small generators.

3 Single-pole switches, double-throw if there are two sets of bus bars. For a three-wire generator or a synchronous converter two single-pole or one double-pole switch may be used, in which case the neutral wire is not brought to the switchboard.
2 Hand-wheels for the field rheostats. But one required if a three-wire generator is used but the two are necessary if the three-wire system is obtained by the use of two generators or a balancer set.
2 Field switches. But one is required for a three-wire generator or synchronous converter.
1 Four-point starting switch. Required only when the machine is to be started as a direct-current motor at times.
2 Potential receptacles, four-point, used in connection with a voltmeter, usually mounted on a swinging bracket. Only one is required for the three-wire generator or the synchronous converter.

An alternating-current generator or a synchronous motor panel for a *three-phase, three-wire system* will require:

3 Ammeters. Only one required for a single-phase panel or for a synchronous motor.
1 Three-phase indicating wattmeter.
1 Voltmeter.
1 8-point potential receptacle used to connect the above voltmeter across any phase. Not necessary for the synchronous motor.
1 Field ammeter. Convenient but not always necessary.
1 Double-pole field switch with discharge clips.
1 Hand-wheel for field rheostat.
1 Synchronizing receptacle.
1 Triple-pole oil switch, usually non-automatic for generators but automatic for motors. This may be single- or double-throw, depending upon the bus bar arrangements.
1 Synchronizer. A single instrument may serve for several machines.
2 Current transformers.
2 Potential transformers. Only one necessary for motor.
1 Power Factor indicator. Not always necessary.
1 Governor control switch. Not always necessary.

Where the switches are of the remote control type, the control switches or the operating handles are mounted on the panel.

A three-phase induction-motor panel should contain:

1 Ammeter.
1 Automatic oil switch, preferably operated by means of an inverse time-limit relay.
The starting compensator used with induction motors is usually mounted independently of the switchboard panel.

The instruments used on a *synchronous converter panel, alternating-current control,* are:

1 Ammeter.
1 Synchronizing receptacle.
1 Oil-switch, automatic.
1 Potential transformer.
2 Current transformers.
1 Switch for control of regulator where a regulator is used and operated by means of a small motor.

A three-phase feeder panel requires:

3 Ammeters. In some cases only one is necessary.
1 Automatic oil switch.
2 Current transformers.
1 Potential Transformer. Not always needed.
1 Voltmeter. Not always needed.
1 Hand-wheel for control of regulator where a regulator is used.

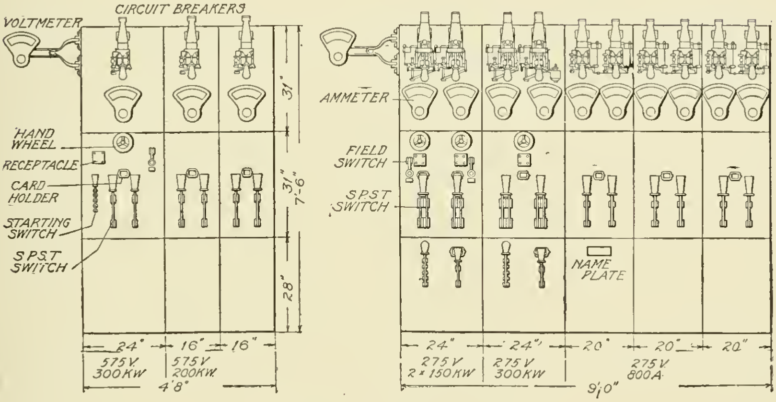


Fig. 24. Standard Switchboard Panel

Direct-Current feeder panels contain:

1 Ammeter. Two are required for a 3-wire feeder.
1 Circuit breaker, single-pole. Two are required for a 3-wire feeder.
1 or more main switches, single-pole or double-pole, and single- or double-throw, depending upon the number of bus bars.
1 Recording wattmeter, not always used.
1 Potential receptacle.
Apparatus for controlling regulators when such are used.

One voltmeter usually serves for several feeder panels, such a meter being mounted above the panels or on a swinging bracket at the end. Switches should preferably be of the quick-break type. Figs. 24 and 25 show some standard switchboard panels as manufactured by the General Electric Company.

Exciter panels are nothing more than generator panels on a small scale. The necessary instruments for a panel controlling one exciter are:

1 Ammeter.
1 Field rheostat.
1 Voltmeter.
1 3-pole switch with fuses.
1 4-point potential receptacle.
1 Equalizing rheostat. This is necessary only where a Tirrill regulator is used and more than one exciter is operated on the same set of excitation buses.

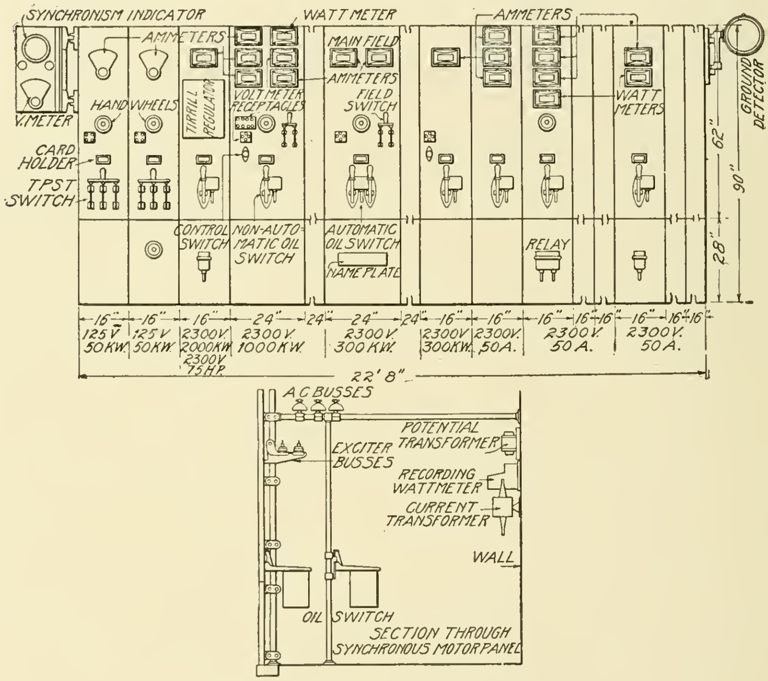


Fig. 25. Standard Switchboard Panel

Total Output Panels contain instruments recording the total power delivered by the plant to the switchboard. The paralleling of alternators is treated in "Management of Dynamo Electric Machinery."

For the higher voltages on alternating-current boards, the measuring instruments are no longer connected directly in the circuit, and the main switch is not mounted directly on the panel. Current and potential transformers, as called for in the lists given in connection with the different panels, are used for connecting to the indicating voltmeters and the ammeters and the recording wattmeters, and potential transformers are used for the synchronizing device.

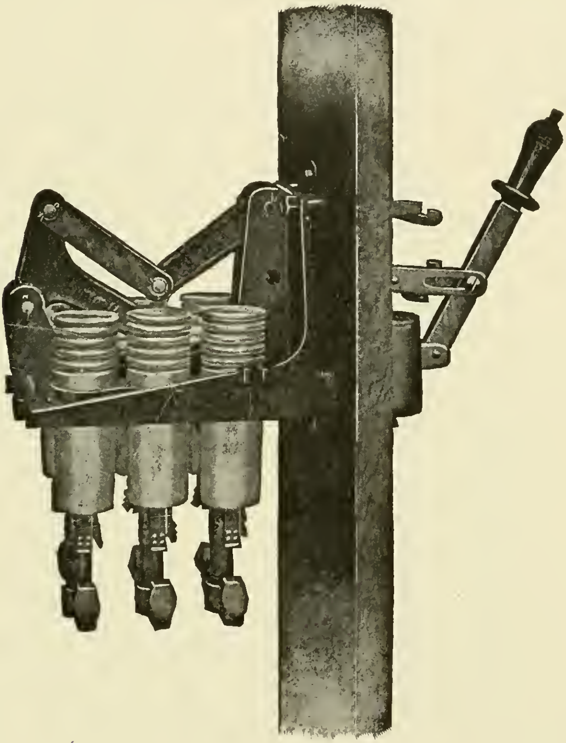


Fig. 26. Three-Phase Oil Switch with Oil Container Removed

These transformers are mounted at some distance from the panel, while the switches may be located near the panel and operated by a system of levers, or they may be located at a considerable distance and operated by electricity or by compressed air.

Oil Switches. Oil switches are recommended for all high potential work for the following reasons:

By their use it is possible to open circuits of higher potential and carrying greater currents than with any other type of switch.

They may be made quite compact.

They may readily be made automatic and thus serve as circuit breakers for the protection of machines and circuits when overloaded.

There are several types of oil switches on the market. A switch constructed for three-phase work, to be closed by hand and to be electrically tripped or opened by hand, is shown in Fig. 26. This shows the switch without the can containing the oil. Fig. 27 shows a similar switch hand-operated, with the can in place. Both of these switches are arranged to be mounted on the panel. Fig. 28 shows how the same switches are mounted when placed at some distance from the panel. For high voltages, they are placed in brick

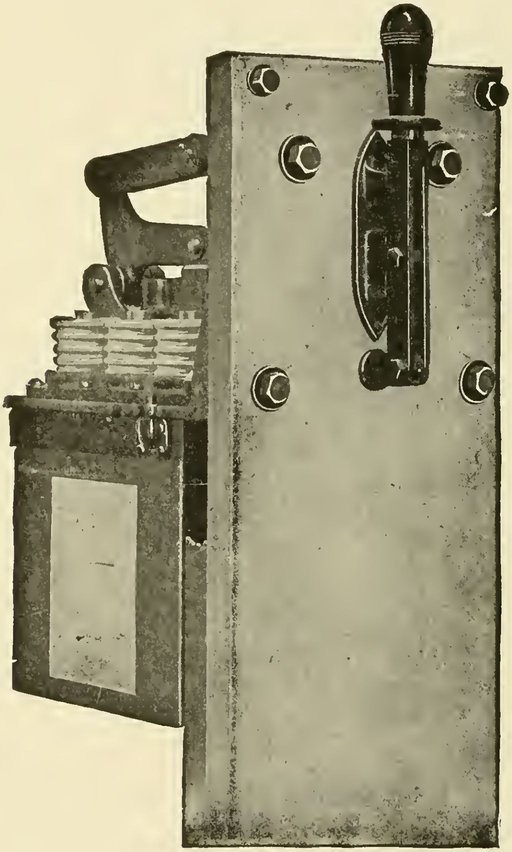


Fig. 27. Three-Phase Oil Switch with Oil Container in Place

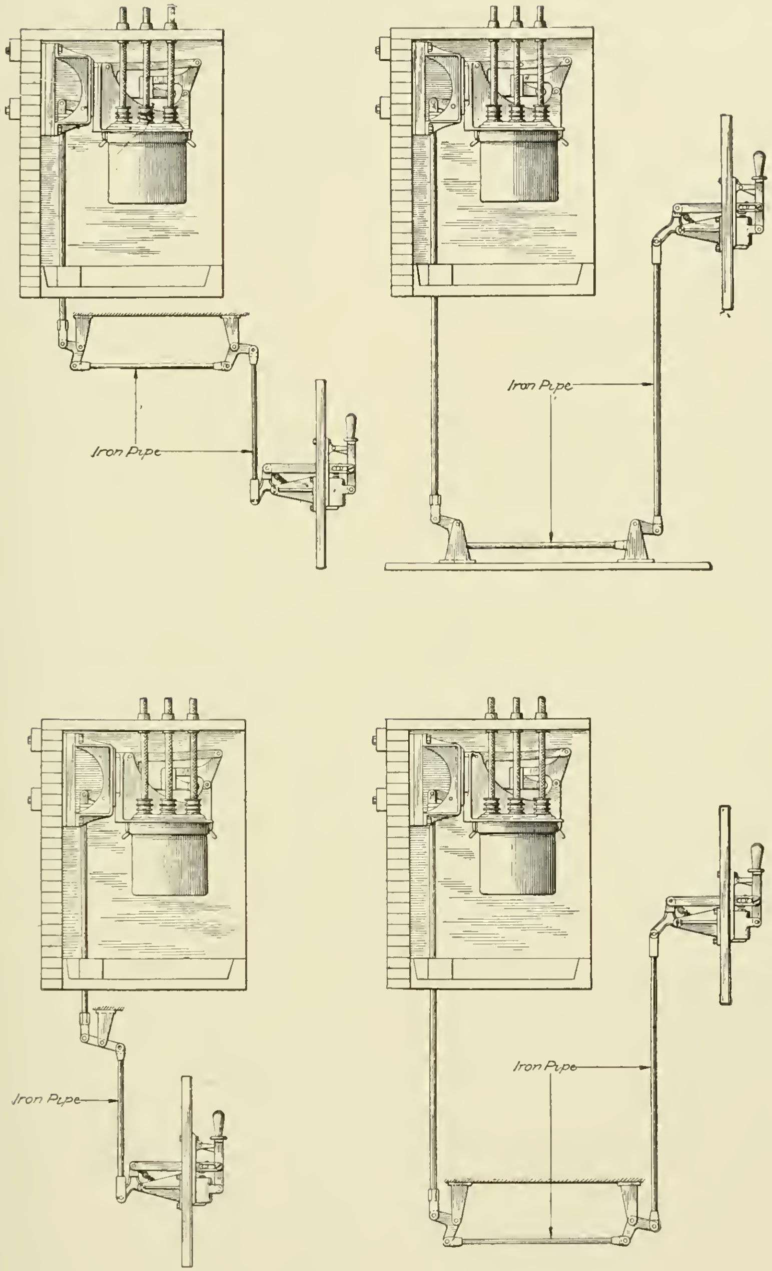


Fig. 28. Four Arrangements of Oil Switch when Mounted at Some Distance from the Panel

cells and often three separate single-pole switches are used, each placed in a separate cell so that injury to the contacts in one leg will in no way affect the other parts of the switch. A form of oil switch used for the higher potentials and currents met with in practice, is shown in Fig. 29. This particular switch is operated by means of an electric motor, though it may as readily be arranged to operate by means of a solenoid or by compressed air. General practice is to place all high-tension bus bars and circuits in separate compartments formed by brick or cement, and duplicate bus bars are quite common.

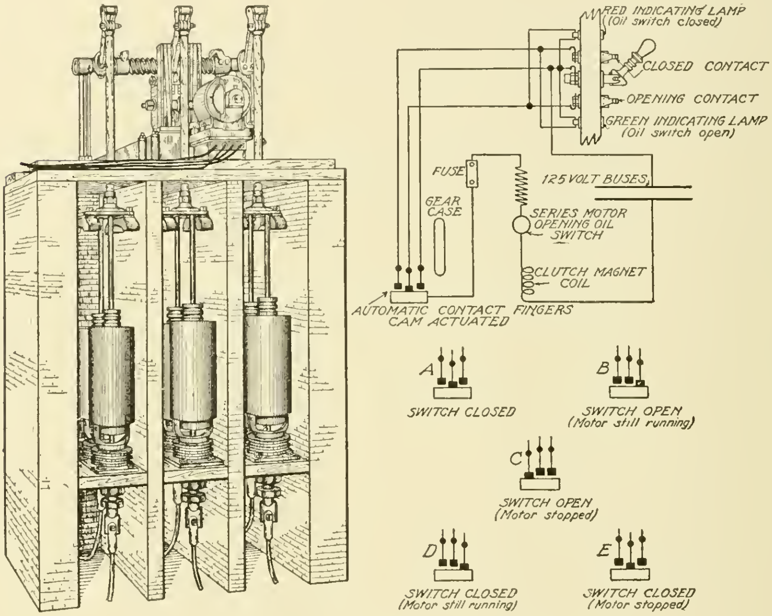

RED INDICATING LAMP (Oil switch closed)
CLOSED CONTACT
OPENING CONTACT
GREEN INDICATING LAMP (Oil switch open)
FUSE
125 VOLT BUSES
GEAR CASE
SERIES MOTOR OPENING OIL SWITCH
CLUTCH MAGNET COIL
AUTOMATIC CONTACT FINGERS CAM ACTUATED
A
SWITCH CLOSED
B
SWITCH OPEN (Motor still running)
C
SWITCH OPEN (Motor stopped)
D
SWITCH CLOSED (Motor still running)
E
SWITCH CLOSED (Motor stopped)

Fig. 29. Form of Oil Switch for High Potentials

Oil switches are made automatic by means of *tripping magnets*, which are connected in the secondary circuits of current transformers, or they may be operated by means of relays fed from the secondaries of current transformers in the main leads. Such relays are made very compact and can be mounted on the front or back of the switchboard panels. The wiring of such tripping devices is shown in Fig. 30.

With remote control of switches, the switchboard becomes in many instances more properly a switch house, a separate building being devoted to the bus bars, switches and connections. In other cases a framework of angle bars or gas pipe is made for the support of the switches, bus bars, current and potential transformers, etc. The supports for the controlling switches are sometimes mounted in a nearly horizontal position, forming the bench type of control board.

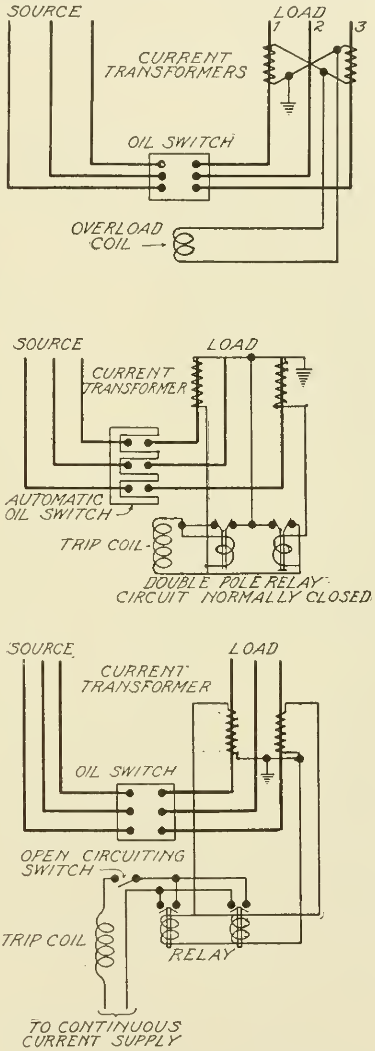


Fig. 30. Wiring Diagram for Tripping Devices

Additional types of panels which may be mentioned are transformer panels, usually containing switching apparatus only, and arc-board panels. The latter are arranged to operate with plug switches. A single panel used in the operation of series transformers on arc-lighting circuits is shown in Fig. 31.

Safety Devices. In addition to the ordinary overload tripping devices which have already been considered, there are various safety devices necessary in connection with the operation of central stations. One of the most important of these is the *lightning arrester*. For direct-current work, the lightning arrester often takes the form of a single gap connected in series with a high resistance and fitted with some device for destroying the arc formed by discharge to the ground. One of these is connected between either side of the circuit and the ground, as shown diagrammatically in

Fig. 32. A "kicking" coil is connected in circuit between the arresters and the machine to be protected, to aid in forcing the lightning discharge across the gap. In railway feeder panels such kicking coils are mounted on the backs of the panels.

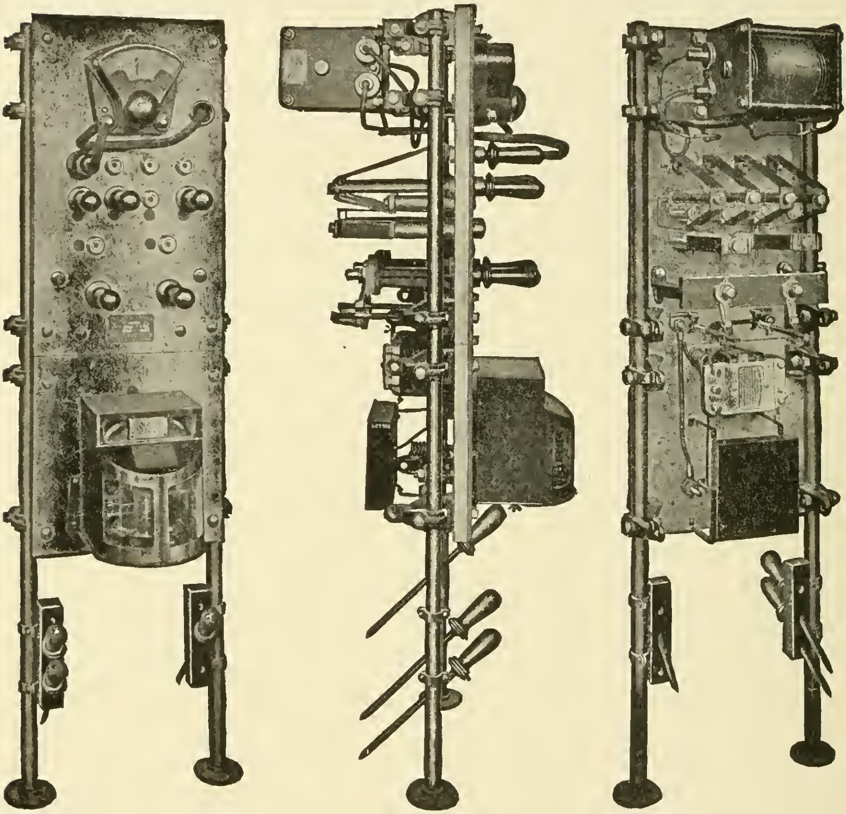


Fig. 31. Single Panel for Series Transformers in Arc-Lighting Circuits

For alternating-current work, several gaps may be arranged in series, these gaps being formed between cylinders of "non-arcing" metal. High resistances and reactance coils are used with these, as in direct-current arresters. Fig. 33 shows connections for a 10,000-volt lightning arrester. The resistance used in connection with lightning arresters are of special design and non-inductive. In recent types these resistances are connected in shunt to the gaps as shown in Fig. 34. Lightning arresters should always be provided with knife blade switches so that they can be disconnected from the circuit for inspection and repairs. A typical installation of lightning arresters is shown in Fig. 35.

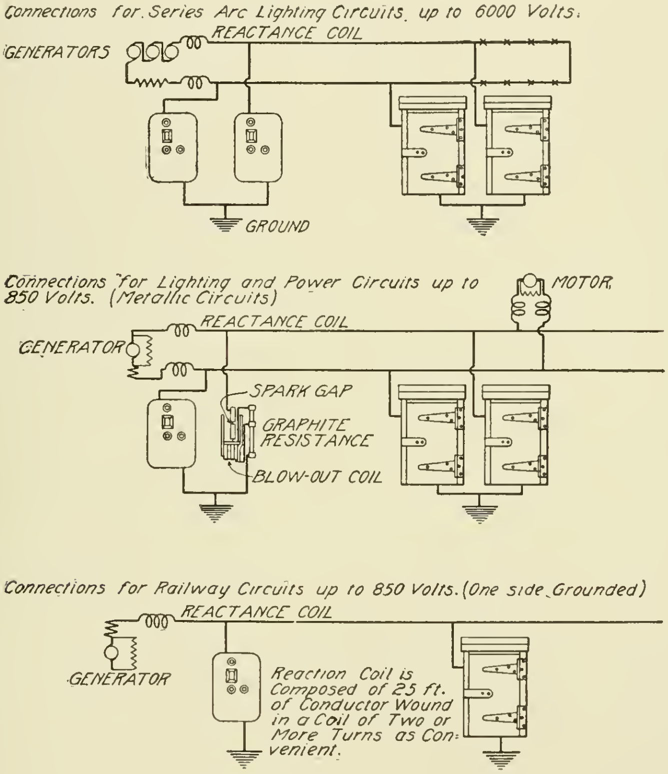

Connections for Series Arc Lighting Circuits up to 6000 Volts.
REACTANCE COIL
GENERATORS
GROUND
Connections for Lighting and Power Circuits up to 850 Volts. (Metallic Circuits)
MOTOR
REACTANCE COIL
GENERATOR
SPARK GAP
GRAPHITE RESISTANCE
BLOW-OUT COIL
Connections for Railway Circuits up to 850 Volts. (One side Grounded)
REACTANCE COIL
GENERATOR
Reaction Coil is Composed of 25 ft. of Conductor Wound in a Coil of Two or More Turns as Convenient.

Fig. 32. Lightning-Arrester Diagrams of D. C. Work

In place of a series of gaps a single gap with terminals made in the form of horns is employed in some cases for lightning protection. Such an arrester is known as a *horn gap*, or *horn arrester*. The gap is connected between the line and the ground and when the potential strain becomes great enough the gap is broken down. The arc formed by the machine current after the gap is broken down

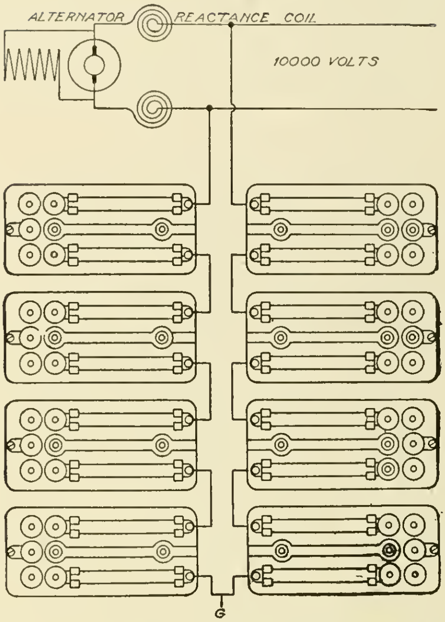


Fig. 33. Connections for 10,000-Volt Lightning Arrester

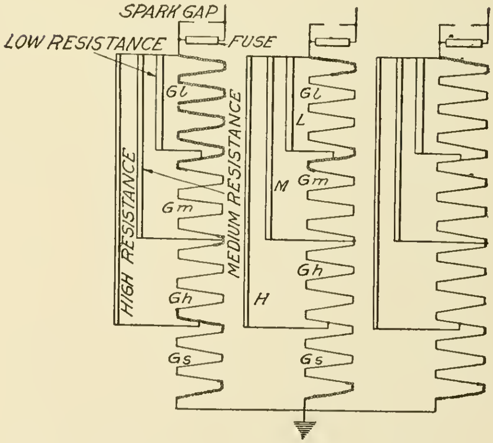


Fig. 34. Non-Inductive Resistances in Shunt with Lightning Arrester

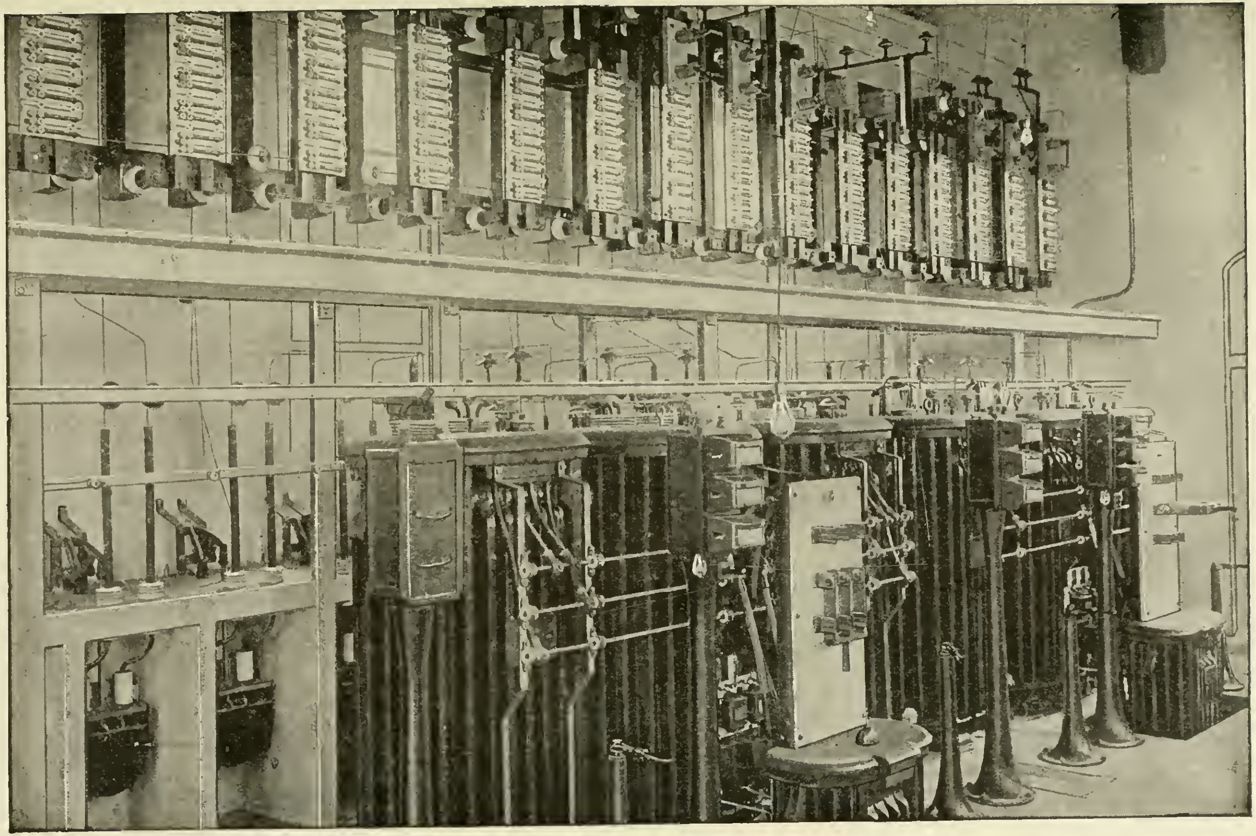


Fig. 35. Typical Installation of Lightning Arresters

rises and lengthens until it can no longer be maintained by the generator or generators in service. The horn arrester as applied to series lighting circuits is shown in Fig. 36. A series resistance, shown in the lower part of the figure, is used with this particular arrester.

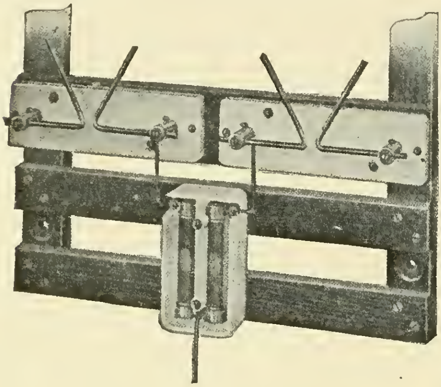


Fig. 36. "Horn" Lightning Arrester

The most recent development in the way of lightning protection is the introduction of the aluminum cell arrester. The elementary cell consists of two aluminum plates, on which a film of aluminum hydroxide is formed, and which are immersed in a suitable electrolyte. The peculiar property of such a cell which makes it useful as a lightning arrester is that it has a high resistance up to a certain potential impressed upon it but when a critical value of voltage is reached, the resistance becomes very low. The critical voltage for a single unit for alternating current is between 335 and 360 volts, and such a cell may be connected to a 300-volt circuit with only a very small current flow. For higher voltages, a number of cells are connected in series and a horn gap is inserted between the arrester and the line wire. The gap prevents any flow of current unless the arrester is brought into action by the discharge of excess line potential, in which case the aluminum cells offer a path of low resistance for the discharge of potential so long as the voltage is in excess of the critical voltage, but the machine or line potential, which is below the critical voltage of the arrester, cannot force enough current through the arrester circuit to maintain the arc at the gap. There is some dissolution of the film of hydroxide if the cell is left standing and not connected to the circuit, but it is readily formed again when the circuit is made. Arresters using a gap should have the gap closed for a short interval daily in order to insure a proper film on the aluminum plates. Views of the aluminum arrester are shown in Figs. 37 and 38.

Reverse-current relays are installed when machines or lines are operated in parallel. If two or more alternators are running and connected to the same set of bus bars, and one of these should fail to generate voltage by the opening of the field circuit, or some other cause, the other machine would feed into this generator and might cause considerable damage before the current flowing would be sufficient to operate the circuit breaker by means of the overload trip coils. To avoid this, reverse-current relays are used. They are so arranged as to operate at, say $\frac{1}{4}$ the normal current of the machine or line, but to operate only when the power is being delivered in the wrong direction.

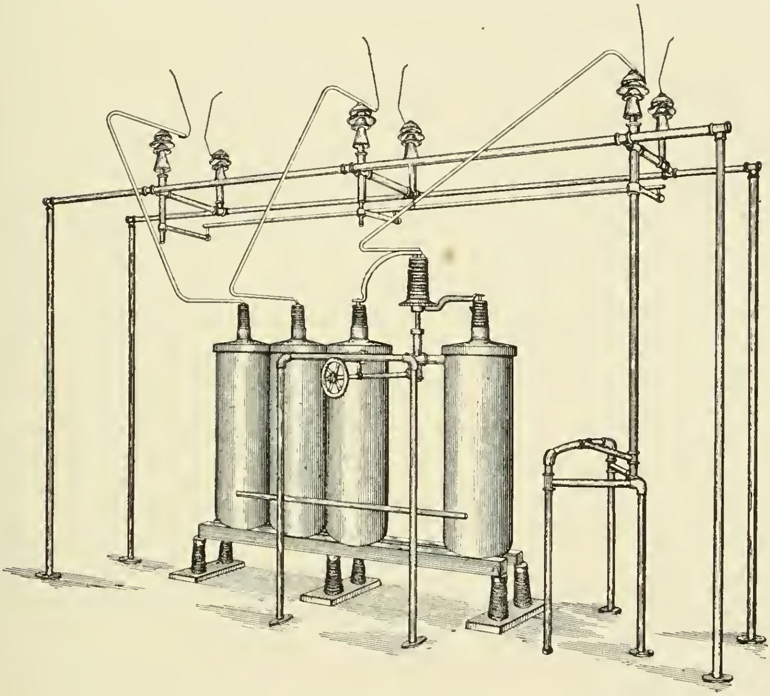


Fig. 37. Installation of Aluminum Lightning Arrester for 35,000 Volts

Speed-limit devices are used on both engines and rotary converters to prevent racing in the one case and running away in the second. Such devices act on the steam supply of engines and on the direct-current circuit breakers of rotary converters, respectively.

Complete wiring diagrams for standard switchboards are shown in Figs. 39 and 40.

SUBSTATIONS

Substations are for the purpose of transforming the high potentials down to such potentials as can be used on motors or lamps, and in many cases to convert alternating current into direct current. Step-down transformers do not differ in any respect from step-up transformers. Either motor-generator sets or rotary converters may be used to change from alternating to direct current. The former consist of synchronous or induction motors, direct connected to direct-current generators, mounted on the same bedplate. The generator may be shunt or compound wound, as desired. Rotary or synchronous converters are direct-current generators, though specially designed; and they are fitted with collector rings attached to the winding at definite points. The alternating current is fed into these rings and the machine runs as a synchronous motor, while direct current is delivered at the commutator end. There is a fixed relation between the voltage applied to the alternating-current side and the direct-current voltage, which depends on the shape of the wave form, losses in the armature, pole pitch of the machine, method of connection, etc. The generally accepted values are given in Table XIII.

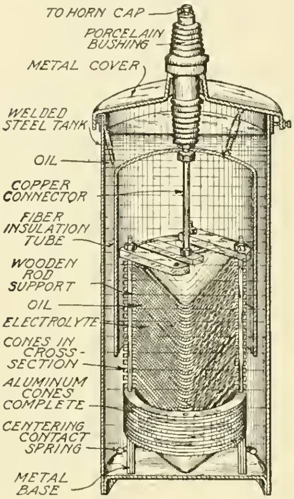


Fig. 38. Cross-Section of Aluminum Arrester

The increase of capacity of six-phase machines over other machines of the same size is given in Table XIV.

This increase is due to the fact that, with a greater number of phases, less of the winding is traversed by the current which passes through the converter. The saving by increasing the number of phases beyond six is but slight and the system becomes too complex. Rotary converters may be over-compounded by the addition of series fields, provided the reactance in the alternating circuits be of a proper value. It is customary to insert reactance coils in the leads from the low-tension side of the step-down transformers to the collector rings to bring the total reactance to a value which will insure

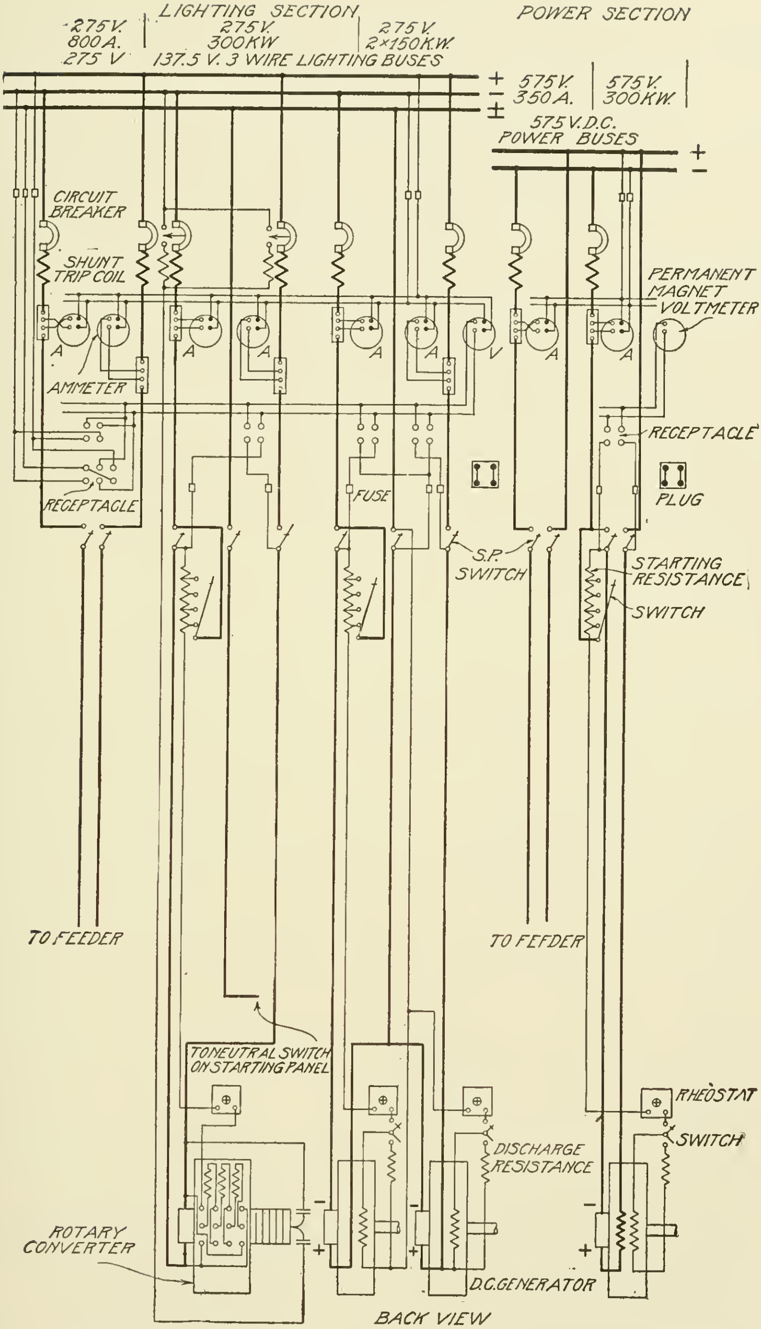


Fig. 39. Wiring Diagram for Standard Switchboard

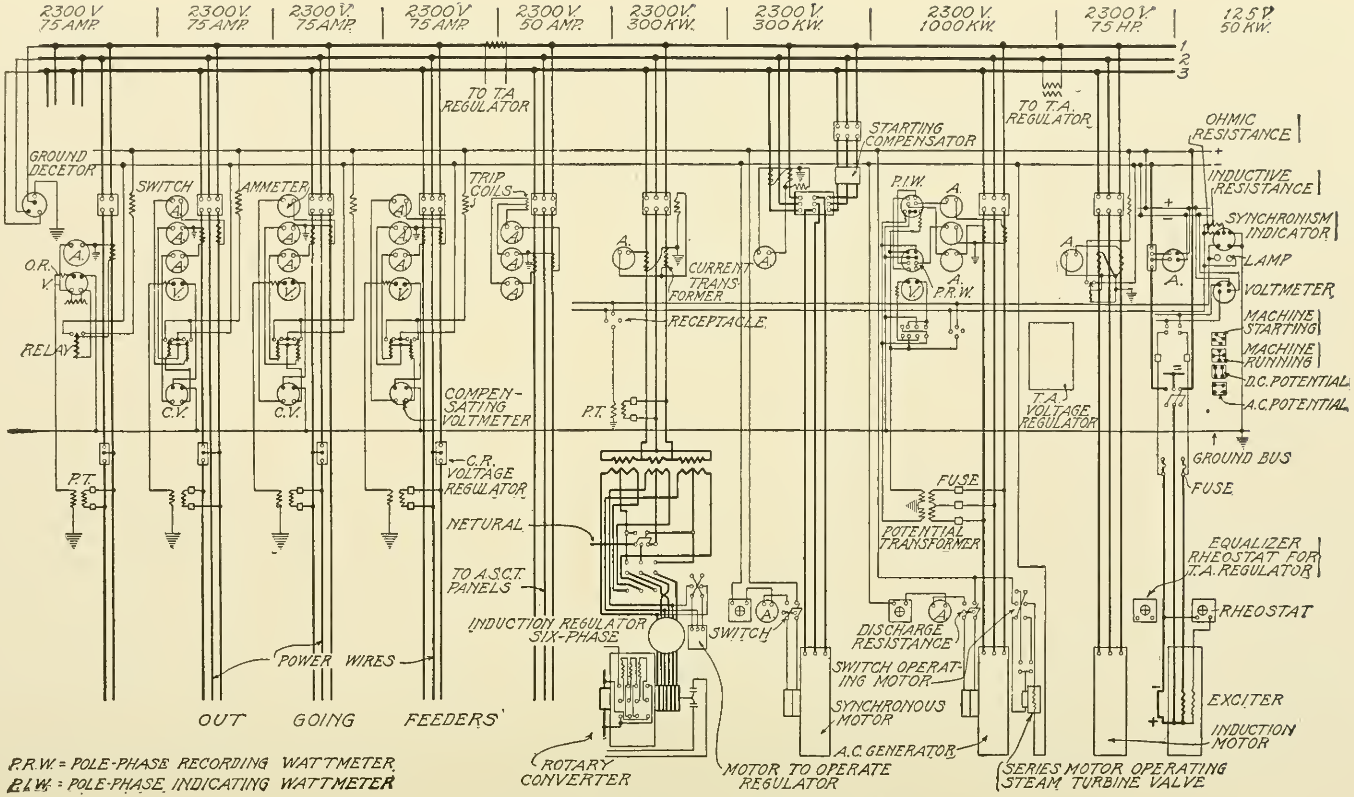


Fig. 40. Wiring Diagram for Standard Switchboard

TABLE XIII

Full Load Ratios

Current		Potential Per Cent
Continuous		100
Two-phase and Six-phase (diametrical)	550 volts	72.5
	250 volts	73
	125 volts	73.5
Three-phase and Six-phase (Y or delta)	550 volts	62
	250 volts	62
	125 volts	63

the desired compounding. Again, the voltage may be controlled by means of induction regulators placed in the alternating-current leads.

Two other methods of potential regulation for synchronous converters are in use. In the first of these methods a series generator is used, this generator consisting of a polyphase armature attached to the rotary converter shaft and revolving in a separate field. The phases of this armature are connected between the collector rings of the machine and the taps to the converter armature, and the voltage impressed upon the converter taps amounts to the line voltage plus or minus the potential developed in the regulating armature. By means of a suitable field rheostat for the regulating field, any ordinary range of direct current at the brushes of the converter can be obtained with a constant voltage of alternating-current supply. Fig. 41 shows a converter equipped with this regulating device.

In the regulating-pole converter each pole of the machine is made up of two parts, the main pole and the regulating pole. By

TABLE XIV

Capacity Ratios

Continuous-current generator	100
Single-phase converter	85
Two-phase converter	164
Three-phase converter	134
Six-phase converter	196

varying the excitation of the regulating pole the ratio of conversion between the alternating-current voltage and the direct-current voltage can be changed through a considerable range—a sufficient range to cover the requirements ordinarily required in practice. Fig. 42 shows a view of a regulating pole converter. Motor-generators are more costly and occupy more space than rotary converters but the regulation of the voltage is much better and they are to be preferred for lighting purposes.

BUILDINGS

The power station usually has a building devoted entirely to this work, while the substations, if small, are often made a part of other buildings. While the detail of design and construction of the buildings for power plants belongs primarily to the architect, it is the duty of the electrical engineer to arrange the machinery to the best advantage, and he should always be consulted in regard to the general plans, at least, as this may save much time and expense in the way of necessary modifications. The general arrangement of the machinery will be taken up later, but a few points in connection

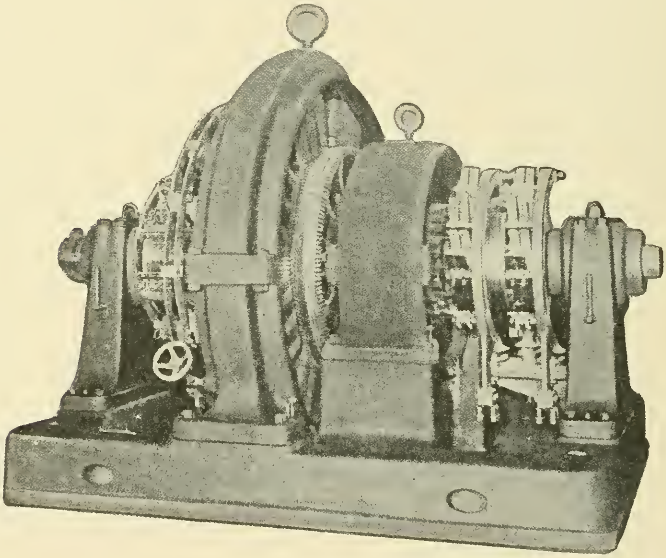


Fig. 41. Rotary Converter Equipped with Regulating Generator

with the construction of the buildings and foundations will be considered here.

Space must be provided for the boilers—this may be a separate building—engine and dynamo room, general and private offices, store rooms and repair shops. Very careful consideration should be given to each of these departments. The boiler room should be parallel with the engine room, so as to reduce the necessary amount of steam piping to a minimum, and if both rooms are in the same building a brick wall should separate the two, no openings which would allow dirt to come from the boiler room to the engine room being allowed. The height of both boiler and engine rooms should be such as to allow ample headway for lifting machinery and space for placing and repairing boilers, while provision should be made for extending these rooms in at least one direction. Both engine and boiler rooms should be fitted with proper traveling cranes to facilitate the handling of the units. In some cases the engines and dynamos occupy separate rooms, but this is not general practice. Ample light is necessary, especially in the engine rooms. The size of the offices, store rooms, etc., will depend entirely on local conditions.

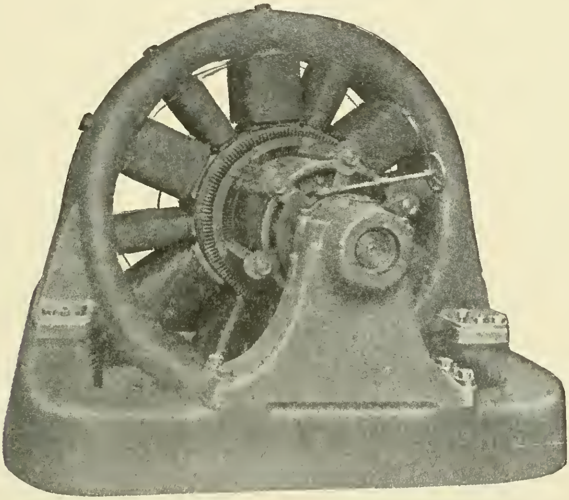


Fig. 42. Regulating-Pole Rotary Converter

TABLE XV

Thickness of Walls for Power Plants

Width of Building clear between walls	Height of Wall	First Section		Second Section		Third Section	
		Height	Thickness	Height	Thickness	Height	Thickness
25 feet	40 feet	40 feet	12 inches				
25 feet	40-60 feet	40 feet	16 inches	To top	12 inches		
25 feet	60-75 feet	25 feet	20 inches	To top	16 inches		
25 feet	75-85 feet	20 feet	24 inches	20-60 ft.	20 inches	To top	16 inches
25 feet	85-100 ft.	25 feet	28 inches	25-50 ft.	24 inches	50-75 feet	20 inches

NOTE. With clear space exceeding 25 feet the walls should be made 4 inches thicker for each 10 feet or fraction thereof in excess of 25 feet. For buildings greater than 100 feet in height, each additional 25 feet or fraction thereof next above the curb shall be increased 4 inches in thickness.

Foundations. The foundations for both the walls and the machinery must be of the very best. It is well to excavate the entire space under the engine room to a depth of eight to ten feet so as to form a basement, while in most cases the excavations must be made to a greater depth for the walls. Foundation trenches are sometimes filled with concrete to a depth sufficient to form a good underfooting. The area of the foundation footing should be great enough to keep the pressure within a safe limit for the quality of the soil. The walls themselves may be of wood, brick, stone, or concrete. Wood is used for very small stations only, while brick may be used alone or in conjunction with steel framing, the latter construction being used to a considerable extent. If brick alone is used, the walls should never be less than twelve inches thick, and eighteen to twenty inches is better for large buildings. They must be amply reinforced with pilasters. Stone is used only for the most expensive stations.

Table XV, which is taken from the New York Building Laws, may serve as a guide to the thickness of walls for power plants. The interior of the walls is formed of glazed brick, when the expense of such construction is warranted. In fireproof construction, which is always desirable for power stations, the roofs are supported by steel trusses and take a great variety of forms. Fig. 43 shows what has been recommended as standard construction for lighting stations, showing both brick and wood construction. The floors of the engine room should be made of some material which will not form grit or dust. Hard tile, unglazed, set in cement or wood floors, is desirable. Storage battery rooms should be separate from all others and should have their interior lined with some material which will not be affected by the acid fumes. The best of ventilation is desirable for all parts of the station, but is of particular importance in the dynamo room if the machines are being heavily loaded. Substation construction does not differ from that of central stations when a separate building is erected. They should be fireproof if possible.

The foundations for machinery should be entirely separate from those of the building. Not only must the foundations be stable, but in some locations it is particularly desirable that no vibrations be transmitted to adjoining rooms and buildings. A loose or sandy soil does not transmit such vibrations readily, but firm earth or rock transmits them almost perfectly. Sand, wool, hair, felt, mineral wool, and asphaltum concrete are some of the materials used to prevent this. The excavation for the foundation is made from 2 to 3 feet deeper and 2 to 3 feet wider on all sides than the foundation, and the sand, or whatever material is used, occupies this extra space.

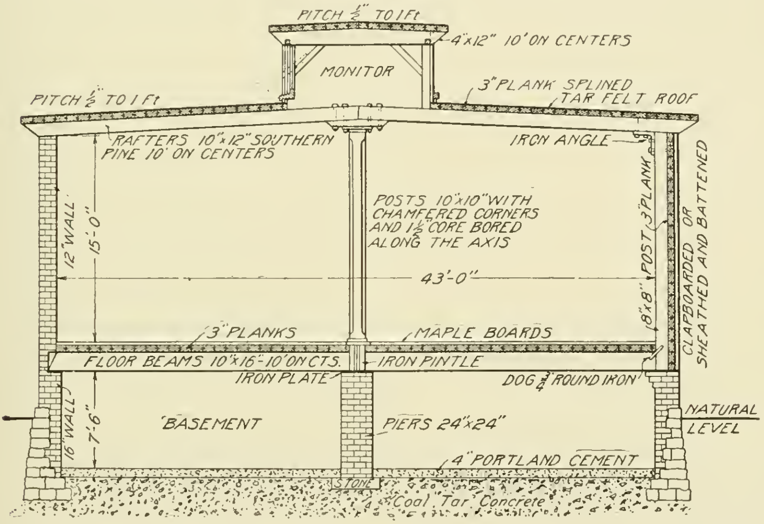


Fig. 43. Standard Construction for Lighting Station. Brick and Wood Construction

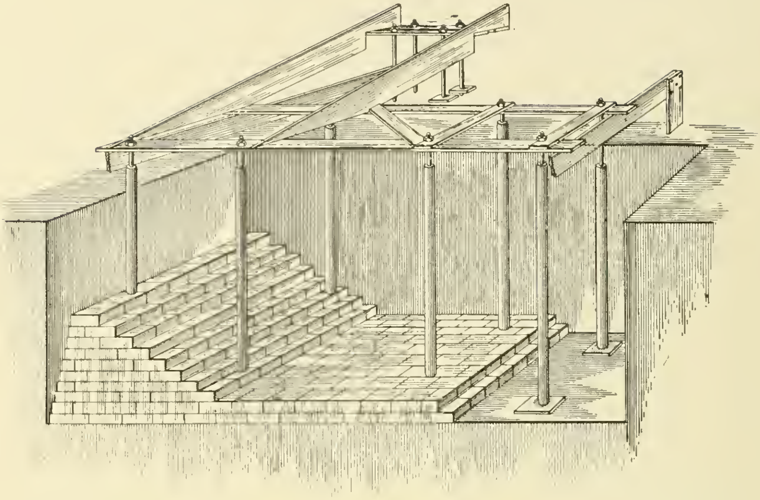
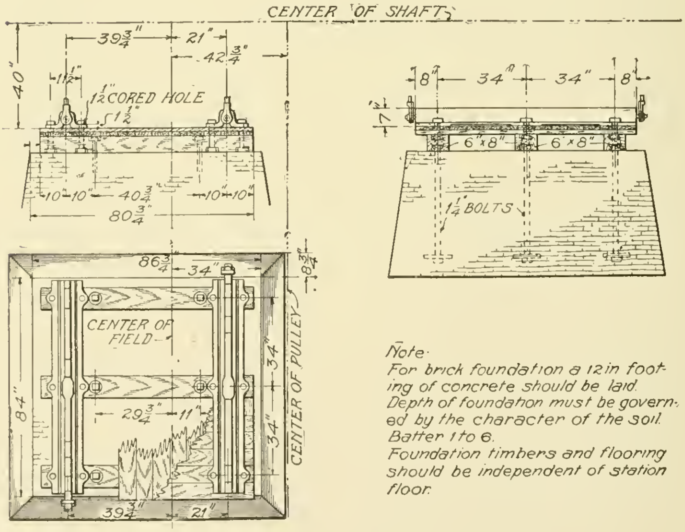


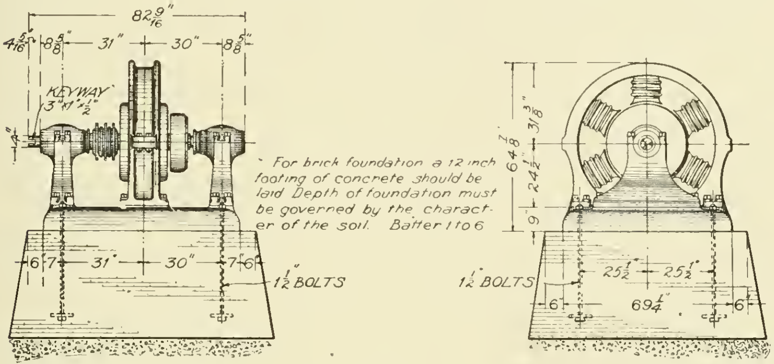
Fig. 44. Foundation for Machines Showing Use of Template and Iron Pipe for Holding Bolts



Note·
For brick foundation a 12 in footing of concrete should be laid.
Depth of foundation must be governed by the character of the soil.
Batter 1 to 6.
Foundation timbers and flooring should be independent of station floor.

Fig. 45. Foundation for 150-Kw. Generator

Brick, stone, or concrete is used for building up the greater part of machinery foundations, the machines being held in place by means of bolts fastened in masonry. A template, giving the location of all bolts to be used in holding the machine in place, should be furnished, and the bolts may be run inside of iron pipes with an internal diameter a little greater than the diameter of the bolt. This allows some play to the bolt and is convenient for the final alignment of the machine. Fig. 44 gives an idea of this construction. The brickwork should consist of hard-burned brick of the best quality, and should be laid in cement mortar. It is well to fit brick or concrete foundations with a stone cap, forming a level surface on which to set the machinery, though this is not neces-



* For brick foundation a 12 inch footing of concrete should be laid Depth of foundation must be governed by the character of the soil. Batter 1 to 6

Fig. 46. Foundation for Rotary Converter

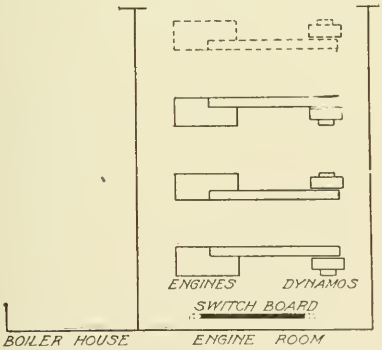


Fig. 47. Diagram of Simple Arrangement of Belted Machines

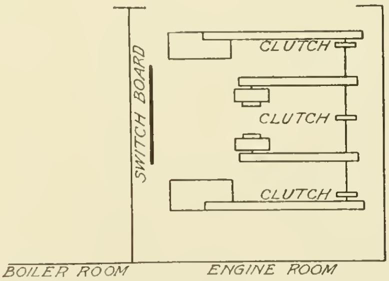


Fig. 48. Diagram of Arrangement of Machines Using Jack Shaft

sary. Generators are sometimes mounted on wood bases to furnish insulation for the frame. Fig. 45 shows the foundation for a 150-kw. generator, while Fig. 46 shows the foundation for a rotary converter.

Station Arrangement. A few points have already been noted in regard to station arrangement, but the importance of the subject demands a little further consideration. Station arrangement depends chiefly upon two facts—the location and the machinery to be installed. Undoubtedly the best arrangement is with all of the machinery on one floor with, perhaps, the operating switchboard mounted on a gallery so that the attendants may have a clear view of all the machines. Fig. 47 shows the simplest arrangement of a plant using belted machines. Fig. 48 shows an arrangement of units where a jack shaft is used. Direct-current machines should be placed so that the brushes and commutators are easily accessible and the switchboard should be placed so as not to be liable to accidents, such as the breaking of a belt or a flywheel.

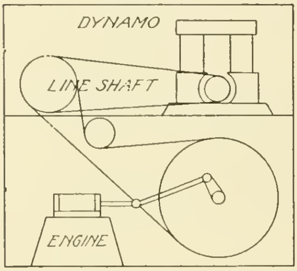


Fig. 49. Diagram of Double-Deck Arrangement of Machines

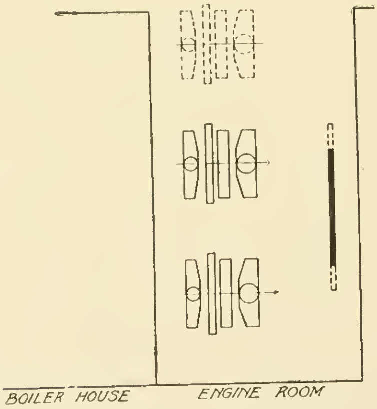


Fig. 50. Diagram of Station Using Direct-Connected Units

When the cost of real estate prohibits the placing of all of the machinery on one floor, the engines may be placed on the first floor and belted to generators on the second floor, Fig. 49. It is always desirable to have the engines on the main floor, as they cause considerable vibration when not mounted on the best of foundations. The boilers, while heavy, do not cause such vibration and they may be placed on the second or third floor. Belts should not be run vertically, as they must be stretched too tightly to prevent slipping.

Fig. 50 shows a large station using direct-connected units, while Figs. 51 and 52 show the arrangement of the turbine plant of the Boston Edison Electric Illuminating Company. This station will contain twelve large turbine units when completed. Note the arrangement of boilers when several units are required for a single prime mover.

The use of the steam turbine has led to the introduction of a type of station known as a *double-deck power plant* and used in some instances where it is desirable to save space. In this type of station the boilers are placed on the ground floor and the turbines, which are of the horizontal type, are placed on a second floor directly above the boilers. Since there is but little vibration to the turbines and only light foundations are necessary, this construction may be readily carried out. Fig. 53 shows the general arrangement of such a plant. The use of a separate room or building for the cables, switches, and operating boards is becoming quite common for high-tension generating plants. The remarkable saving in floor space brought about by the turbine is readily seen from Fig. 54. The total floor space occupied by the 5,000 kw. units of the Boston station is 2.64 square feet per kw. This includes boilers—of which there are eight, each 512 h. p. for each unit—turbines, generators, switches, and all auxiliary apparatus. For the 10,000 and 15,000 kw. turbine sets now coming into use, this figure is still further reduced.

When transformers are used for raising the voltage, they may be placed in a separate building, as is the case at Niagara Falls, or the transformers may be located in some part of the dynamo room, preferably in a line parallel to the generators.

Fig. 55 shows the arrangement of units in a hydraulic plant. Fig. 56 is a good example of the practice in substation arrangement. The switchboard is at one end of the room, while the rotary converters and transformers are along either side.

Large cable vaults are installed at the stations operating on underground systems, the separate ducts being spread out, and sheet-iron partitions erected to prevent damage being done to cables which were not originally defective, by a short circuit [in any one feeder.

Station Records. In order to accurately determine the cost of generating power and to check up on uneconomical or improper methods of operation and lead to their improvement, accurately-kept station records are of the utmost importance. Such records

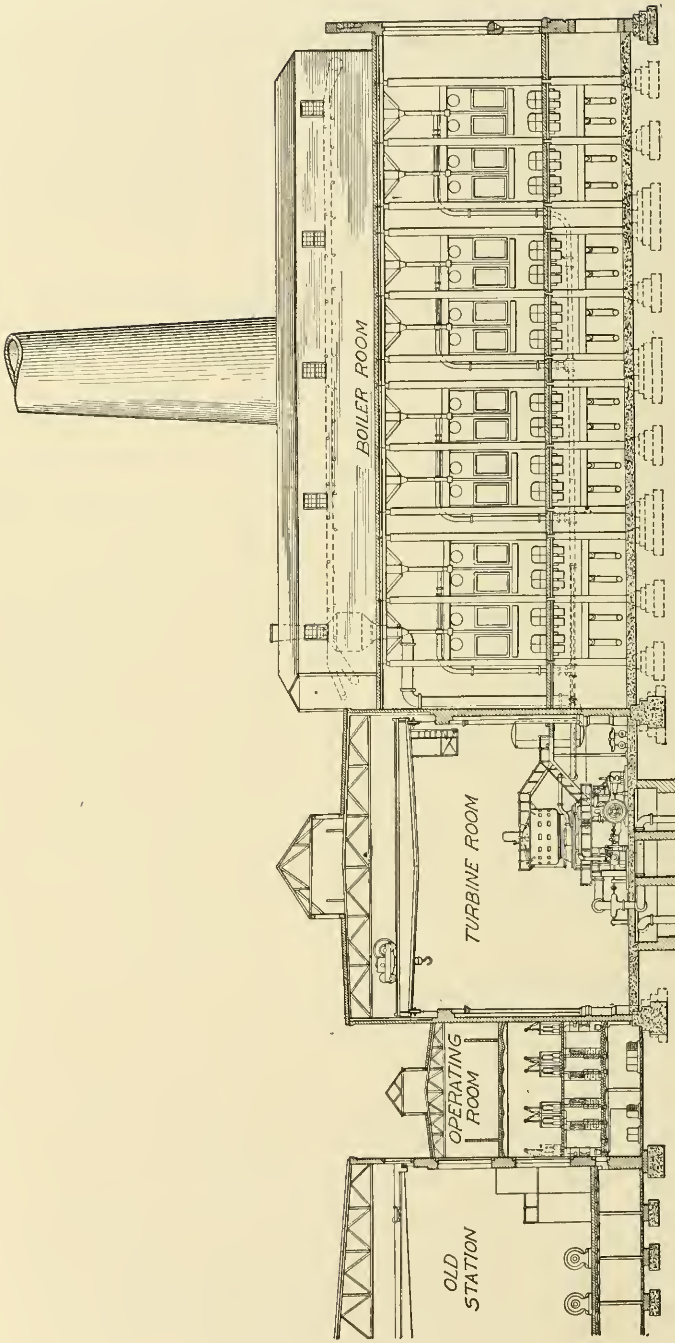
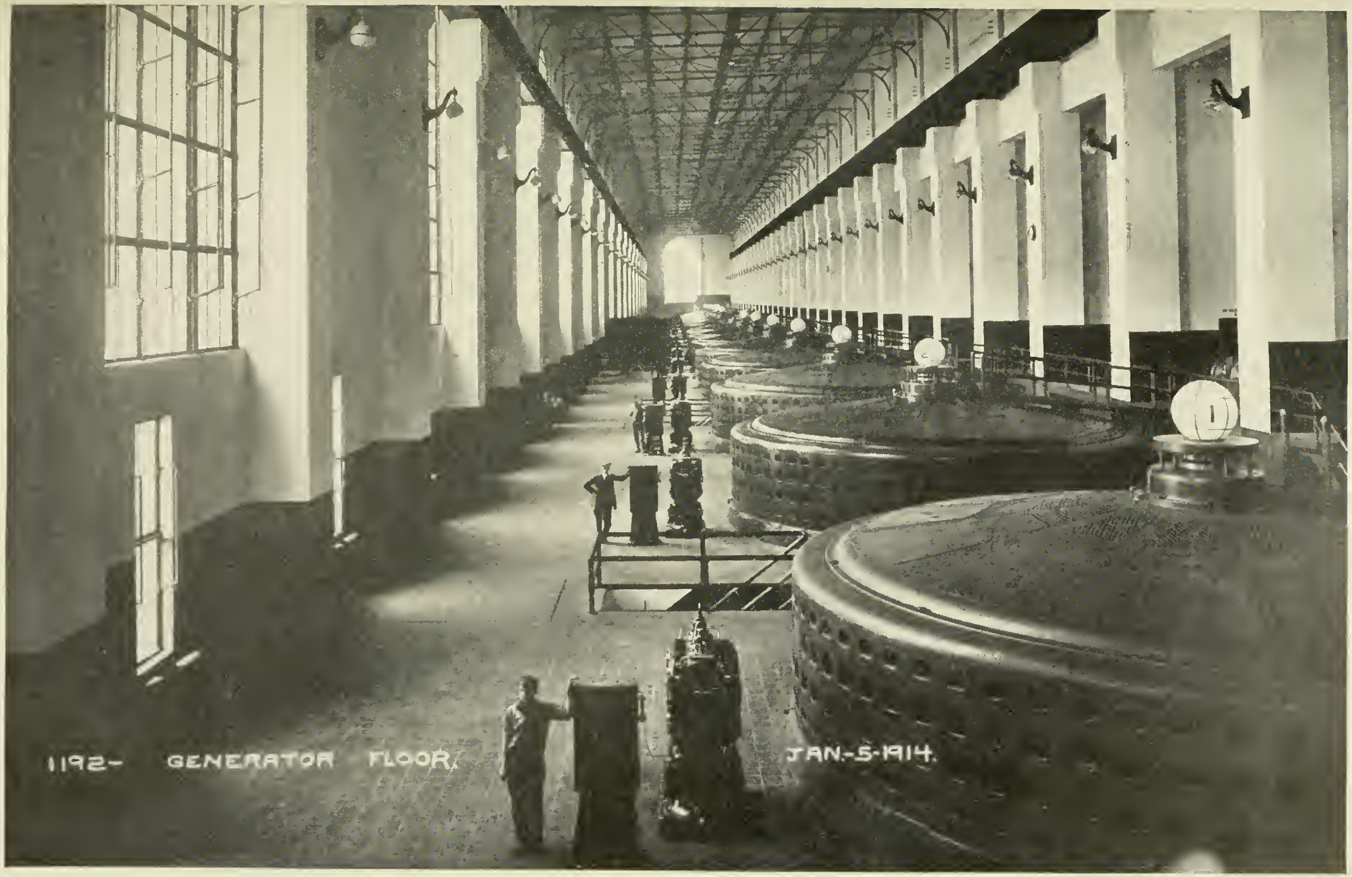


Fig. 51. Part Section of Turbine Plant. Boston Edison Luminating Company



VIEW OF GENERATOR FLOOR OF HALF THE MISSISSIPPI RIVER POWER HOUSE AT KEOKUK, IOWA

Each of the 15 generators shown generates 10,000 horsepower, making the total horsepower of the plant about 300,000.

Photograph by Anschutz, Keokuk, Iowa

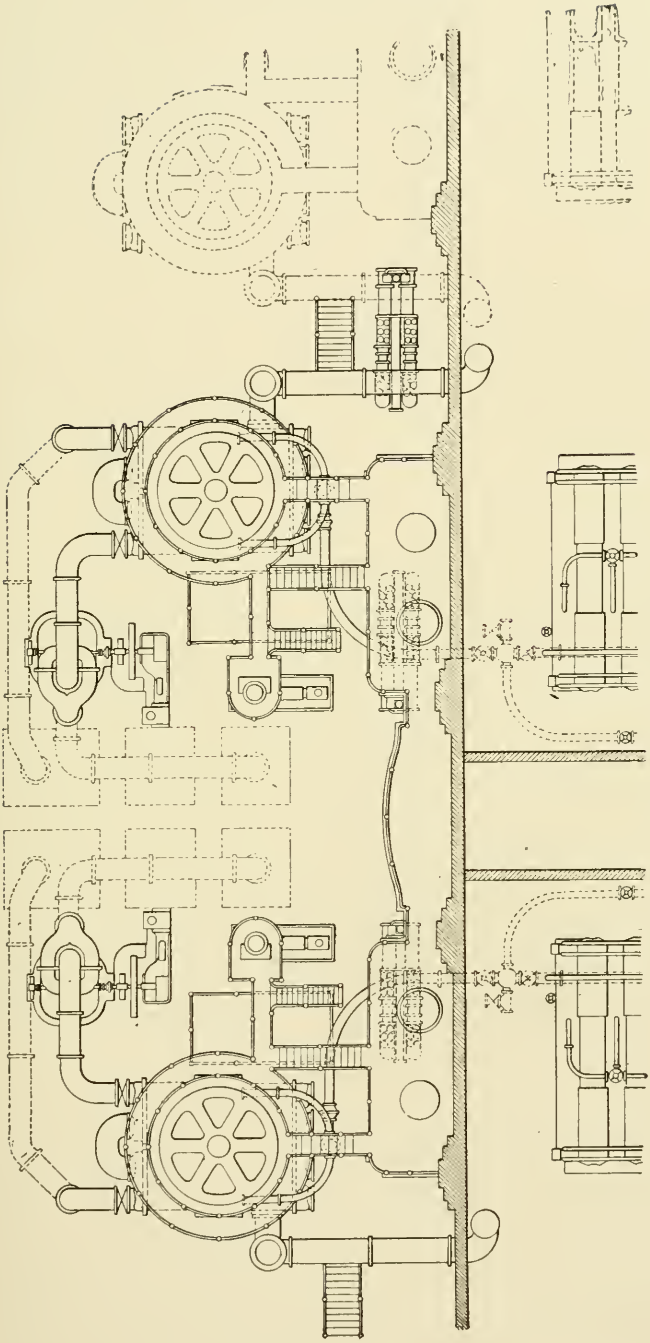


Fig. 52. Plan of Turbines of Fig. 51

should consist of switchboard records, engine-room records, boiler-room records, and distributing-system records. Such records accurately kept and properly plotted in the form of curves, serve admirably for the comparison of station operations from day to day and for the same periods for different years. It pays to keep these records even when additional clerical force must be employed.

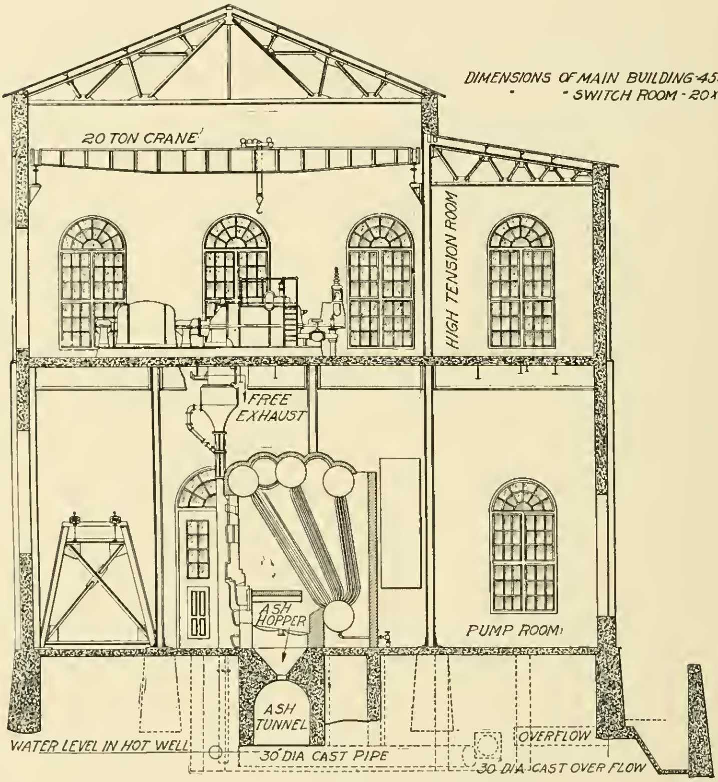


Fig. 53. Double-Deck Turbine Plant

In some states stations furnishing light or power to the public are required to make annual reports and the system of records, accounting, and form of report are all prescribed by the state.

Switchboard records consist, in alternating stations, of daily readings of feeder, recording wattmeters, and total recording wattmeter, together with voltmeter and ammeter readings at intervals of about 15 minutes, in some cases, to check upon the average power factor and determine the general form of the load curve. For direct-current lighting systems, volt and ampere readings serve to give the true output of the stations, and curves are readily plotted from these readings. The voltage should be recorded for the bus bars as well as for the centers of distribution.

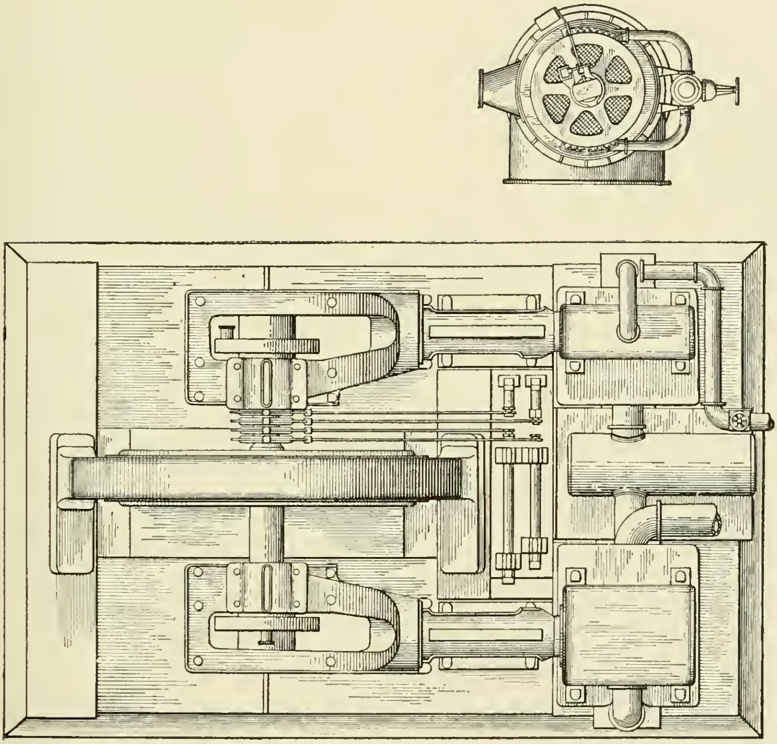


Fig. 54. Space Occupied by Turbo-Alternator Compared with that of Generator and Reciprocating Engine of Same Capacity

Indicator diagrams should be taken from the engines at frequent intervals for the purpose of determining the operation of the valves. Engine-room records include labor; use of waste, oil, and supplies; as well as all repairs made on engines, dynamos and auxiliaries.

Boiler-room records include labor and repairs, amount of coal used, which amount may be kept in detail if desirable, amount of water used, together with steam-gauge record and periodical analysis of flue gases as a check on the methods of firing.

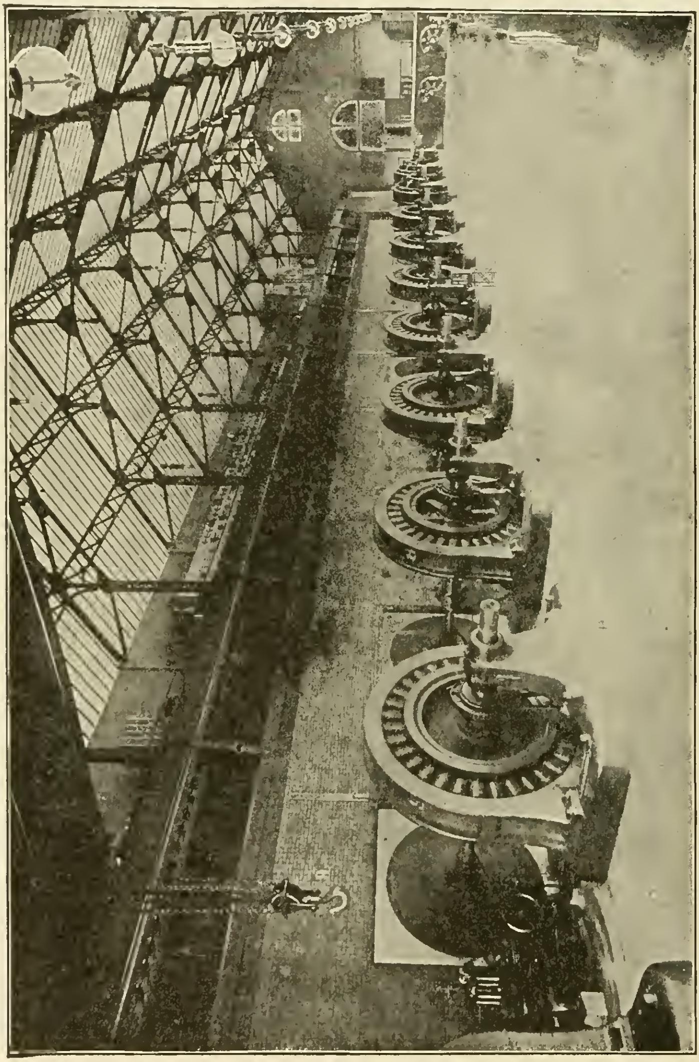


Fig. 55. Arrangement of Units in a Hydraulic Plant

Records for the distributing system include labor and material used for the lines and substations. For multiple-wire systems, frequent readings of the current in the different feeders will serve as a check on the balance of the load.

The cost of generating power varies greatly with the rate at which it is produced as well as upon local conditions. Station-operating expenses include cost of fuel, water, waste, oil, etc., cost of repairs, labor, and superintendence. Fixed charges include insurance, taxes, interest on investment, depreciation, and general office expenses. Total expenses divided by total kilowatt-hours gives the cost of generation of a kilowatt-hour. The cost of distributing a kilowatt hour may be determined in a similar manner. The rate of depreciation of apparatus differs greatly with different machines, but the following figures may be taken as average values, these figures representing percentage of first cost to be charged up each year:

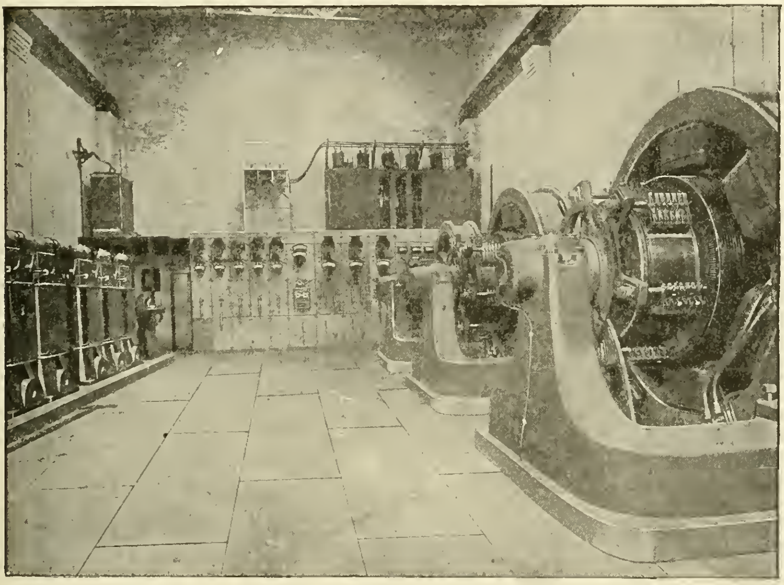


Fig. 56. A Good Arrangement of Apparatus for Substation

Fireproof buildings from 2 to 3 per cent.
Frame buildings from 5 to 8 per cent.
Dynamos from 2 to 4 per cent.
Prime movers from $2\frac{1}{2}$ to 5 per cent.
Boilers from 4 to 5 per cent.
Overhead lines, best constructed, 5 to 10 per cent.
More poorly constructed lines 20 to 30 per cent.
Badly constructed lines 40 to 60 per cent.
Underground conduits 2 per cent.
Lead covered cables 2 per cent.

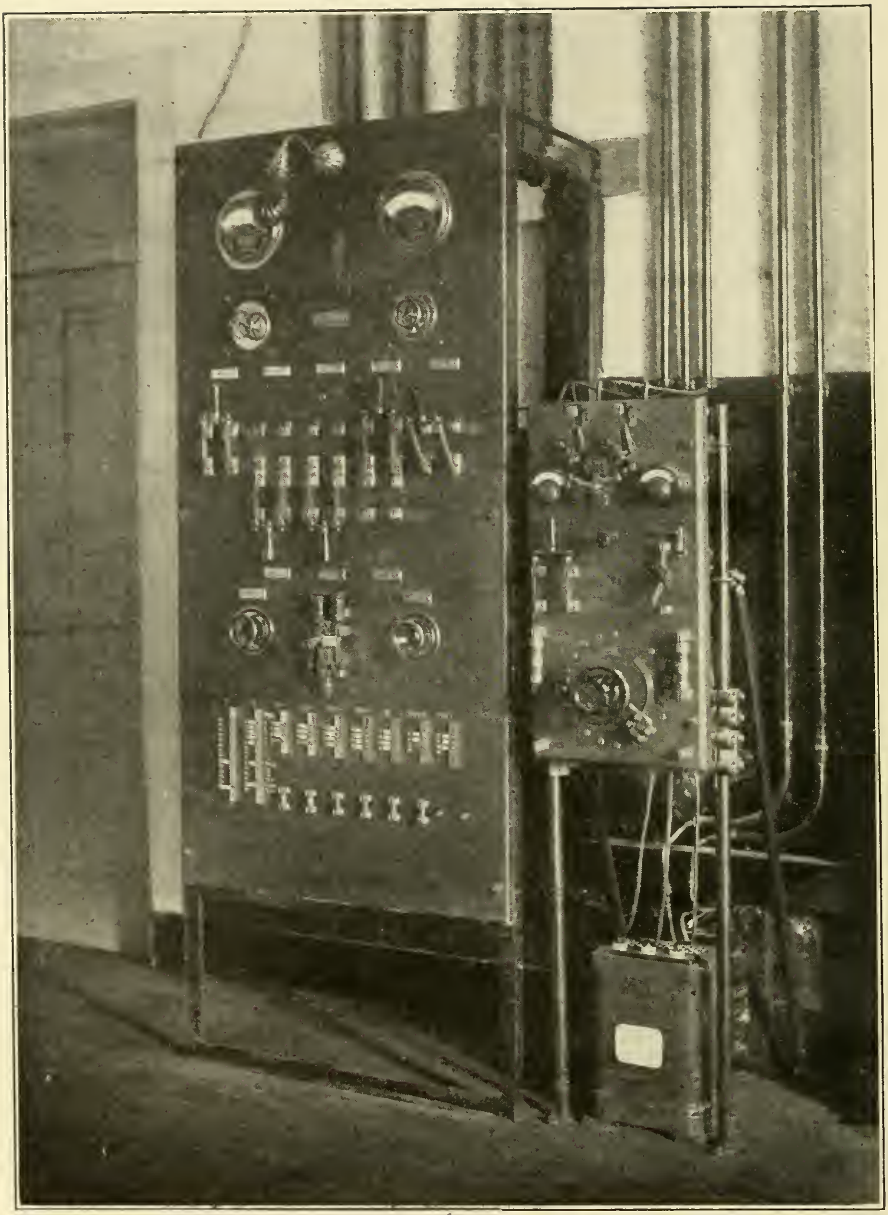
Methods of Charging for Power. There are four methods used for charging consumers for electrical energy, namely, *the flat-rate, or contract, system, the meter system, the two-rate meter system,* and *a system by which each customer pays a fixed amount depending on the maximum demand and in addition pays at a reasonable rate for the power actually used.*

In the flat-rate system, each customer pays a certain amount a year for service, this amount being based on the estimated amount of power to be used. These rates vary, depending on the hours of the day during which the power is to be used, being greatest if the energy is to be used during peak hours. It is an unsatisfactory method for lighting service, as many customers are liable to take advantage of the company, burning more lights than contracted for and at different hours, while the honest customer must pay a higher rate than is reasonable in order to make the station operation profitable. This method serves much better when the power is used for driving motors, and is used largely for this class of service.

The simple meter method of charging serves the purpose better for lighting, but the rate here is the same no matter what hour of the day the current is used. Obviously, since machinery is installed to carry the peak of the load, any power used at this time tends to increase the capital outlay from the plant, and users should be required to pay more for the power at such times. The meter system is often employed with a sliding scale or rate, the rate charged per kw.-hour depending upon the amount of electrical energy used.

The two-rate meter accomplishes this purpose to a certain extent. The meters are arranged so that they record at two rates, the higher rate being used during the hours of heavy load.

There are several methods of carrying out the fourth scheme. In the Brighton System a fixed charge is made each month, depending on the maximum demand for power during the previous month, a regular schedule of such charges being made out, based on the cost of the plant. An integrating wattmeter is used to record the energy consumed, while a so-called "demand meter" records the maximum rate of demand.



POWER SWITCHBOARD FOR MEDIUM-SIZED OFFICE
Mercury Arc Rectifier Panel and Transformer at Right.

SWITCHBOARDS, SWITCHING, AND PROTECTIVE APPARATUS

INTRODUCTION

The switchboard is the control center for all the principal electrical circuits in the power house. It is the connecting link between the generating apparatus on one hand and the consumer on the other hand. Because of its importance in maintaining service to the distributing system, it has been given a great deal of attention by engineers, always working toward simplicity and reliability.

There is no place in the power station where an operator can do more damage by a mistake due to a misunderstanding of his equipment than at the switchboard. Simplicity, therefore, is of great importance.

Because of the liability of complete suspension of service for more or less lengthy periods, when trouble occurs in the switching equipment, reliability of apparatus should be considered very thoroughly.

It will very often be necessary to balance the advantages of reliability and simplicity against the advantages of special features which may suggest themselves to the owner or operator of switchboards. One should never lose sight of the fact that such special features undoubtedly complicate the equipment and that in most cases such complication is dangerous.

In general the switchboard consists of panels of various forms and materials, mounted on a supporting framework, and carrying the devices used in the switching operations. All other devices used in the collection, division, and distribution of current are

TABLE I

Switchboard Diagram Symbols

Symbol	Appliance	Symbol	Appliance
+	Positive	O.C.	Overload Coil
—	Negative	O.S.	Oil Switch
=	Equalizer	P.F.I.	Power Factor Indicator
±	Neutral	P.I.W.	Polyphase Indicating Wattmeter
A.	Ammeter	P.P.	Potential Plug
A.S.A.	Auxiliary Switch, Alarm	P.P.B.	Push and Pull Button
A.S.C.	Auxiliary Switch, Circuit Closing	P.R.	Potential Receptacle
A.S.O.	Auxiliary Switch, Circuit Opening	P.T.	Potential Transformer
B.A.S.	Bell Alarm Switch	R.	Red
C.	Compensator	RC.	Reactance
C.B.	Circuit Breaker	RE.	Receptacle
C.D.	Curve Drawing	RH.	Rheostat
C.F.	Commutating Field	R.P.	Synchronizing Plug, Running
C.S.	Controlling Switch	RS.	Resistance
C.T.	Current Transformer	S.	Switch
CH.C.	Choke Coil	S.I.	Synchronism Indicator
D.R.	Discharge Resistance	S.P.	Synchronizing Plug, Starting
F.	Fuse	SH.	Shunt
F.A.	Field Ammeter	S.R.	Synchronizing Receptacle
F.I.	Frequency Indicator	T.B.	Terminal Board
F.S.	Field Switch	T.C.	Trip Coil
G.	Green	T.P.B.	Twin Pull Button
G.C.S.	Governor Control Switch	T.S.	Turn Button Switch
G.D.	Ground Detector	V.	Voltmeter
G.L.	Ground Detector Lamp	V.S.	Voltmeter Switch
I.W.	Indicating Wattmeter	W.	Wattmeter
L.	Lamp	W.C.I.	Wattless Component Indicator
L.A.	Lightning Arrester	WH.M.	Watt-hour Meter
L.S.	Limit Switch		
L.V.R.	Low Voltage Release		

mounted on or in connection with the switchboard. In Table I is given a list of symbols which have been adopted by most switchboard manufacturers. These symbols will be used on the diagrams throughout this article.

TYPES

Switchboards may be classified in two different ways as regards their mechanical features: first, as to the form in which they are built, including vertical, bench, and ironclad; and second, as to the way in which the electric circuits are controlled.

Classified as to Form. *Vertical Type.* Vertical switchboards, as the name implies, consist of panels mounted vertically on the framework, and having the various pieces of apparatus mounted on the front and back, Fig. 1.

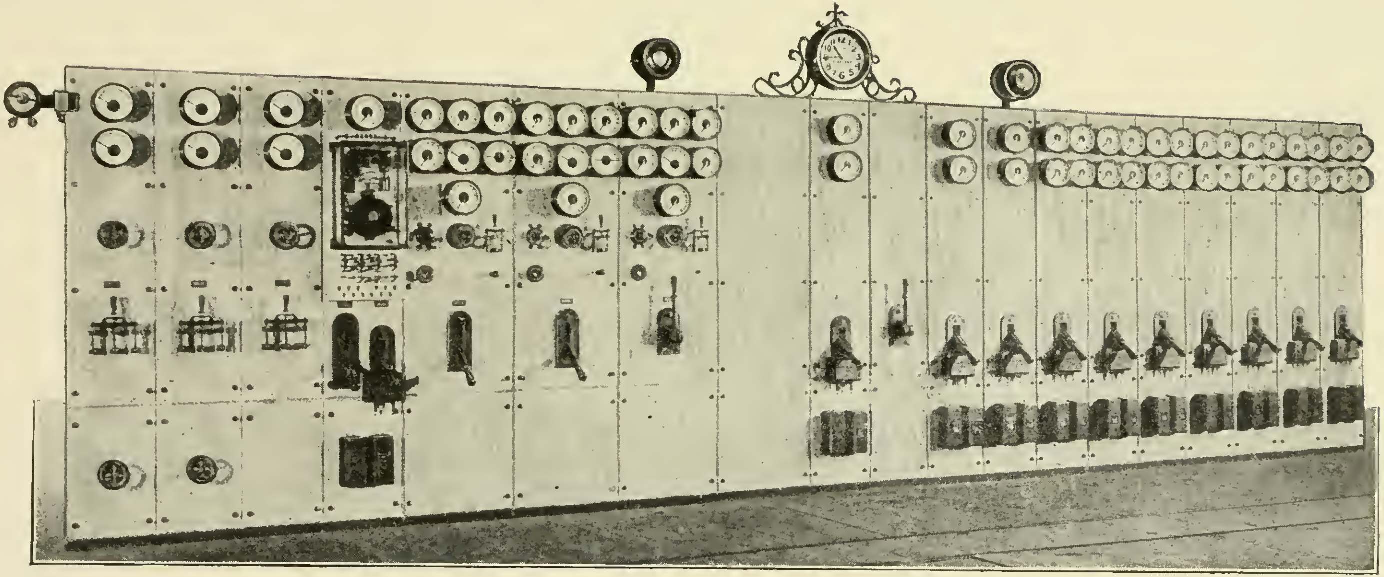


Fig. 1. Vertical Alternating-Current Switchboard
Courtesy of Westinghouse Electric and Manufacturing Company

Bench Type. Bench boards are made up of a horizontal or slightly sloping bench, usually with vertical sub-panels under the front edges, and a vertical section mounted back of the bench. These boards take various forms as to details, but always include the bench and vertical section. The bench is used for mounting the control switches, receptacles, and indicating devices used for operating electrically the main switching apparatus, which is mounted at a distance from the board. The front sub-panels, if they are used, support relays, watt-hour meters, or such apparatus as is not used often. On the upper vertical section is mounted all instrument equipment. Fig. 2 shows one view of a bench board of the

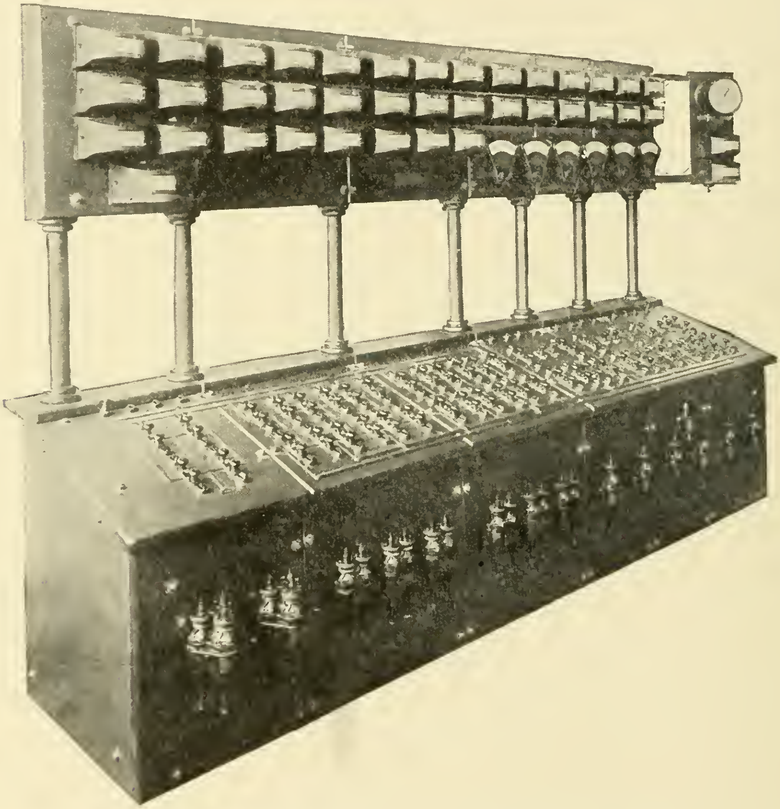


Fig. 2. Bench Type of Switchboard with So-Called "Gallery" Arrangement
Courtesy of General Electric Company

so-called gallery type, in which the instrument section is raised above the bench, so that when mounted on the edge of a gallery overlooking the station, the operator has a practically uninterrupted view of the machines controlled and the operators on the lower floor.

Ironclad Type. Ironclad switchboards are of European origin and have been, as yet, little used in this country. They are used on alternating-current circuits in places where it is considered important that every precaution be taken to prevent accident to those who must work around or near the switchboard. Several forms have been developed. Panels for individual motor circuits are usually made up as steel pedestals carrying an oil switch and an ammeter, all live parts being inside the switch and inside the pedestal. Fig. 3 shows the front and side elevation of such an outfit. Where panels are to be used together, they are usually similar to those shown in Fig. 4. In this type, the instruments, oil switch operating lever, and disconnecting switch operating lever, are mounted on the front of the panel, while the oil switch, disconnecting switches, and all live parts, are mounted back of the panel. The whole equipment at the back is then enclosed in a sheet steel cabinet, as shown. This cabinet may be made in two sections, one containing the buses and main connections, and the other containing the switch. The section of the panel carrying the switch may be mounted on rollers or wheels and arranged to be rolled forward and out of the cabinet, so that all parts can be inspected and repaired. All connections are arranged to be disconnected from the circuit when the panel is pulled out, and an interlock is arranged so that the panel can not be moved unless the disconnecting switches and oil switches are open. With such panels, no live parts are exposed either in front or back, and the whole equipment can easily be connected or disconnected by moving the panel forward or backward.

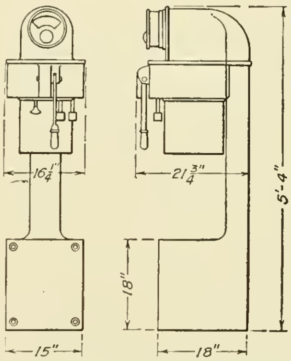


Fig. 3. Single-Panel Switchboard of the Ironclad Type

Classified as to Control. When classified as to control, switchboards may be divided into two sections: direct controlled and remote controlled switchboards.

Direct Control. Direct control switchboards are those in which all switching devices are mounted directly on the panels themselves. These devices may be on the front of the panels and operated directly by handles attached to themselves, as in the case of the ordinary low voltage direct-current circuit breaker. They may be on the front of the panels and operated by handles mounted on the panel and attached to the device by means of an insulating connecting rod, as is sometimes done with high voltage direct-current circuit breakers. They may be on the back of the panel operated in a like manner from handles mounted on the front of the panel.

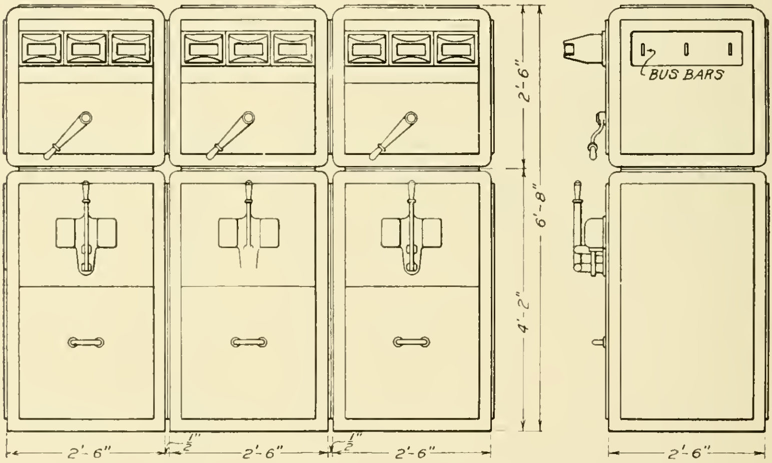


Fig. 4. Front and Side Elevation of Three-Panel Ironclad Switchboard

Remote Control. Remote control boards are those in which the main switching devices are mounted at a distance from the panels. These devices may be operated mechanically, by means of systems of cranks and rods or pipes. In this case, these cranks and rods transmit the motion imparted to an operating lever on the panel to the switch or circuit breaker. They may be operated electrically by means of solenoids or motors. In this case, small control switches are mounted on the panels to direct the current for the closing or opening operation.

One of two reasons is usually responsible for the selection of a remote control switchboard. Either the voltage of the circuits is so high as to be dangerous to life if placed close to the panels, or the size of the switches and connections is so great as to cover the backs of the panels and make an unwieldy and inconvenient arrangement. This latter reason applies with great force to some low voltage alternating-current industrial installations where large amounts of power must be handled and yet where higher voltages are unsafe. For alternating-current circuits, remote control, either mechanical or electrical, usually makes a much cleaner and simpler switchboard, and is to be preferred where it is possible to use it even if other conditions do not require it.

SUPPORTING FRAMEWORK AND PANELS

Steel Frame. Switchboards are almost universally mounted on steel framework, which may be constructed either of *standard angles, channels,* or of *standard gas pipe* with proper fittings. Angle irons (or channels, for heavy equipment) have been used in the past to a great extent and have proven satisfactory. Such construction makes a rigid frame to which panels can be bolted and upon which all sorts of devices may be mounted remote from the panels. Its chief disadvantages are that it is not flexible as regards adjustment, must be drilled differently for each different condition, and looks somewhat crude when complete. Pipe framework is a development of the past few years. Its advocates claim that it has all the advantages of angle iron and none of the disadvantages. Fig. 5 shows a display of the fittings used by the General Electric Company. It will be noted that, with the exception of floor flanges, no threaded fittings are used. This means great flexibility of adjustment. Pipes require practically no threading, and the completed framework when painted presents a neat and substantial appearance, not obtainable in any other way. Tests show that any situation can be taken care of with pipe framework, allowing ample strength and rigidity, and at a cost no greater than with angles or channels.

Materials Used for Panels. Various materials have been tried for the construction of switchboard panels, even including wood, brick, and cement, but slate and marble are the materials most used.

Marble. Marble has been used a great deal because of its good insulating qualities and fine appearance. When apparatus carrying a 2300-volt current is mounted on the panels, it is necessary to use marble or to insulate all live parts from the panels. All engineers now recommend that high voltages be removed from the switchboard entirely. Marble has one marked disadvantage; it absorbs oil and grease rapidly, and there is no way of removing the stains satisfactorily.

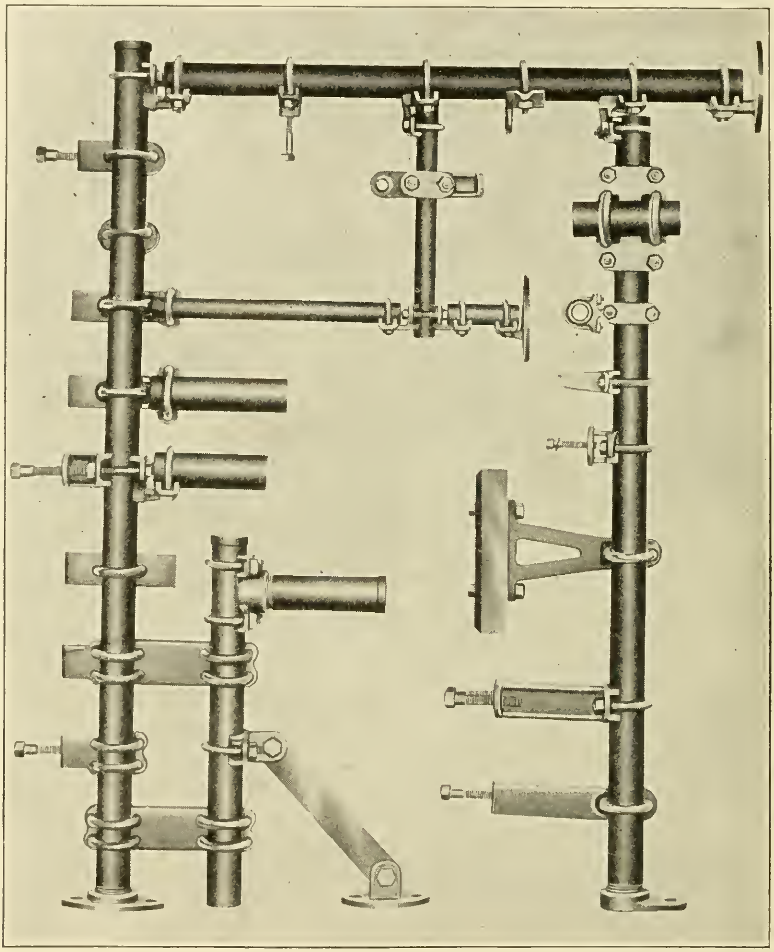
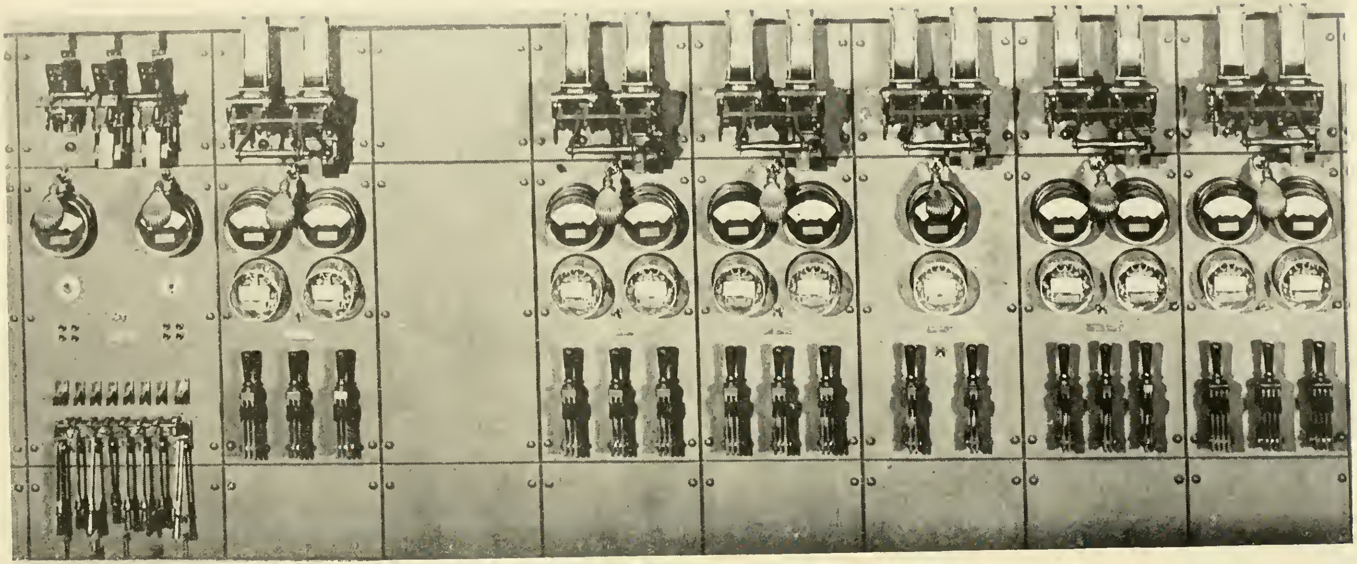


Fig. 5. An Assembly of Switchboard Fittings for Framework
Courtesy of General Electric Company



SWITCHBOARD OF OLIVER OFFICE BUILDING, PITTSBURGH, PENNSYLVANIA

Switchboard was built by the Western Electric Company, Chicago, and handles a power plant of 4000-K.W. capacity.

Courtesy of Roller-Smith Company

Slate. Slate has many advantages over any other material and is being very widely used for switchboards of all kinds. It is exceptionally strong mechanically, especially the better grades. It is obtainable in a neutral black color which will take an oil finish. Such a finish is not affected by the dirt and grease of an engine room and can be cleaned by wiping with oily waste. It is easily cut and drilled and is not apt to be broken by strains caused by bolting the panels to the framework. In appearance, it is thought by some to equal marble. This is especially true when the equipment mounted upon the panels is finished in dead black, with live parts, name plates, etc., finished in copper.

Steel. Steel has been used to some extent for panels, and has some advantages where great strength in resisting shock is necessary.

Summary. The present tendency seems to be toward slate for all installations where utility is the first consideration, although it is often specified where considerable importance is given to appearance. Marble is used a great deal where the switchboard is desired to be an object of display or is considered one of the architectural features, as in office buildings.

FUNDAMENTAL CLASSIFICATION OF SWITCHBOARDS

In general, switchboards may be divided into two fundamental classes, according to the kind of current controlled, viz, direct-current boards and alternating-current boards. In the first case the equipment is comparatively simple, but in the second, many complications arise. Under this latter division, should be included direct-current exciter panels, which, although controlling direct-current, are almost always used in alternating-current plants.

DIRECT=CURRENT SWITCHBOARDS

In considering switchboards for direct current, it will be necessary to subdivide them according to the kind of service for which they are used.

POWER SWITCHBOARDS

In direct-current installations where the current is to be used primarily for power purposes, the potentials generally used are 250 volts or 500 volts, depending on the amount of power and the distance. Simplicity of equipment is probably the most important consideration after one is sure that the apparatus is substantial and reliable. The whole object of the station equipment is to supply power to the motors being driven, and to supply it continuously and without trouble. The switchboard must do its part in maintaining this service, and the equipment on the panels should be ample to give proper protection to machines and feeders, but without complication.

Equipment for Small Generators. *Not Operating in Parallel.* Direct-current generators for power only are always two-wire, and almost always compound wound. The switchboard equipment usually considered necessary to protect small machines of such type not operating in parallel, is as follows:

1 Double-pole single-throw fused lever switch
1 Ammeter
1 Voltmeter

The field rheostat is also mounted on the panel and usually placed back of it with the handwheel on the front.

With the above equipment, the machine is protected from overload or short circuit beyond the switch by means of the fuses. The voltmeter gives an indication of the proper voltage, as it is adjusted by means of the field rheostat; and the ammeter shows just how much current is being supplied to the circuit. A typical wiring diagram for such a simple switchboard equipment is shown in Fig. 6.

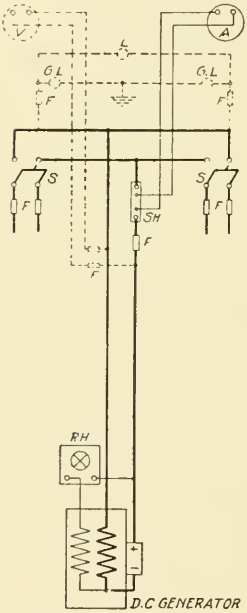


Fig. 6. Wiring Diagram for Small Generator Equipment

Operating in Parallel. When two such machines are operated in parallel, Fig. 7, it is necessary to add another pole to the switch on each generator panel, to make the connection for equalization. This pole need not be fused. On 500-volt machines, either the switches are made quick-break or single-pole switches are used. When two machines are operated thus in parallel, it is necessary to have separate fused switches for the feeders.

In connection with the parallel operation of direct-current generators, it is well to consider the operation necessary to place two such machines together with the least disturbance to the system.

With shunt wound machines, the voltage of the incoming machine can be adjusted with the field rheostat to very near the voltage of the running machine. The incoming machine can then be thrown in parallel with the other one, but will take no load. No disturbance will occur, since both machines are at the same voltage before and after the switch is closed. The load can then be adjusted by means of the rheostat until the two machines are dividing the load properly.

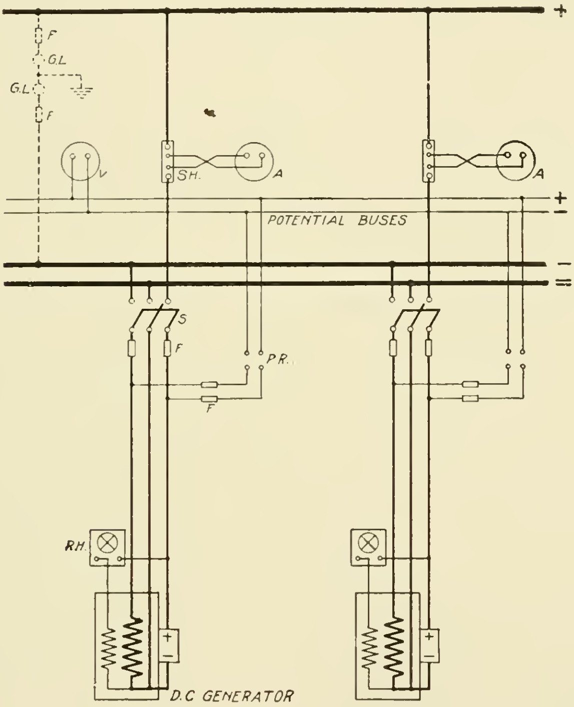


Fig. 7. Typical Wiring Diagram for Switchboard Equipment for Generators Wired in Parallel

With compound wound machines, the conditions are somewhat different, since the series field keeps the voltage up or even increases it beyond the voltage obtained without load when the shunt field alone is acting. When two compound wound machines are paralleled as if they were shunt wound machines, the voltage on the incoming machine is too high, since the series field begins to work as soon as it is paralleled with the field of the running machine and the incoming machine takes all the load. There might also be considerable voltage disturbance on the whole system. The only way in which any of the compounding effect can be obtained before paralleling is to arrange to put the series field in parallel with the series field of the running machine before the two are thrown together. For small machines, these considerations are not so important, but on large machines they should always be taken into account. Such machines should have three single-pole switches, so that the two switches connected to the series field can first be closed, throwing the field in parallel with that of the running machine. The voltage can then be adjusted, the circuit breaker closed, and finally the third lever switch closed. This series of operations gives the minimum of voltage disturbance and requires less adjustment than any other arrangement to bring the loads to their proper value.

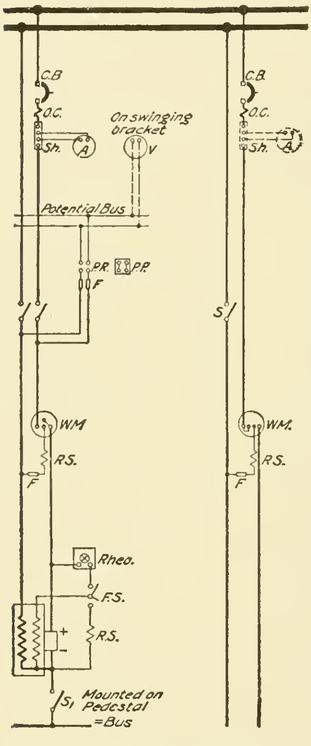


Fig. 8. Switchboard Wiring Diagram for Large Generator Equipment

Equipment for Large Generators. For larger machines, fused switches do not give satisfactory protection, and circuit breakers are almost universally used. The equipment then consists of:

1 Single-pole overload circuit breaker
1 Ammeter
1 Voltmeter
1 Rheostat handwheel
1 Triple-pole, or 3 single-pole, lever switches

Fig. 8 shows a diagram of the connections of such an equipment, except that the voltmeter is supplied for several generators and arrangements are made for "plugging" it on to any one of the circuits. It will be seen that, with this equipment, protection against overload or short circuit is on the positive side only. It is true that a short circuit from the wiring between the positive terminal of the machine and the circuit breaker to any other negative wire would leave the machine without protection; yet, the possibility of such a condition arising is so remote that it is not considered necessary to put a circuit breaker in the opposite side. The National Board of Fire Underwriters approves connections as shown, although some cities, having special rules, require two circuit breakers. With large machines, the length of cable required to bring the equalizer connection to the switchboard may be considerable. In such installations, the equalizer switch is usually mounted near the machine, either on a pedestal or on the frame of the machine itself. A cable is then used for the equalizer bus and run under the floor close to the machines. In paralleling two machines with this equipment, the series field of the incoming machine is thrown in parallel with that of the running machine, by means of the negative and equalizer switches, the circuit breaker is closed, the voltage adjusted, and the positive switch closed. After all the switches are in, the load can be adjusted by means of the field rheostats.

Equipment on Feeder Circuits. On feeder circuits for power purposes, Fig. 9, in medium and large size installations, circuit breakers are usually considered economical, since there are no fuses to buy and less time is required to put a feeder back in service. The equipment would consist of:

1 Single-pole overload circuit breaker (positive)
1 Single-pole lever switch (negative)
1 Ammeter (optional)

This is the simplest equipment possible and is all that is necessary in most cases. As stated above, some cities require two circuit breakers, and in such cases, the switch could just as well be omitted, and the circuit breaker used, one pole at a time, for closing the circuit. The ammeter gives a valuable indication, but it is not always absolutely necessary.

Equipment for Motors. Small and medium sized motors do not require panels that might be considered under the subject of switchboards, but the larger motors do. As an example of what is done sometimes to make a large direct current motor "fool proof", the illustration, Fig. 10, shows a panel built for service in a large mill where the motors were started by unskilled labor. In this equipment, the various devices were interlocked, so that the operator could not start the motors unless everything was done in the right order. Moving the starting switch would not have any effect unless the operator had first pushed the starting

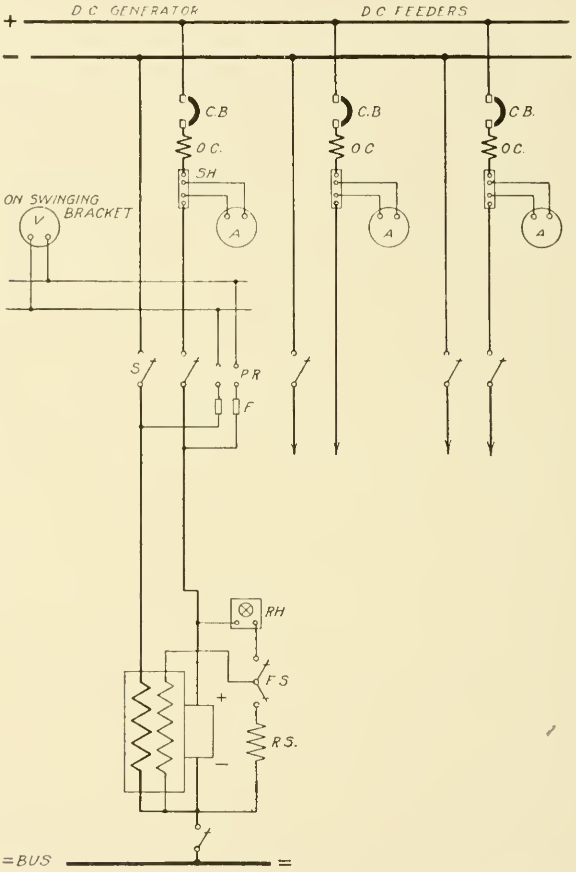
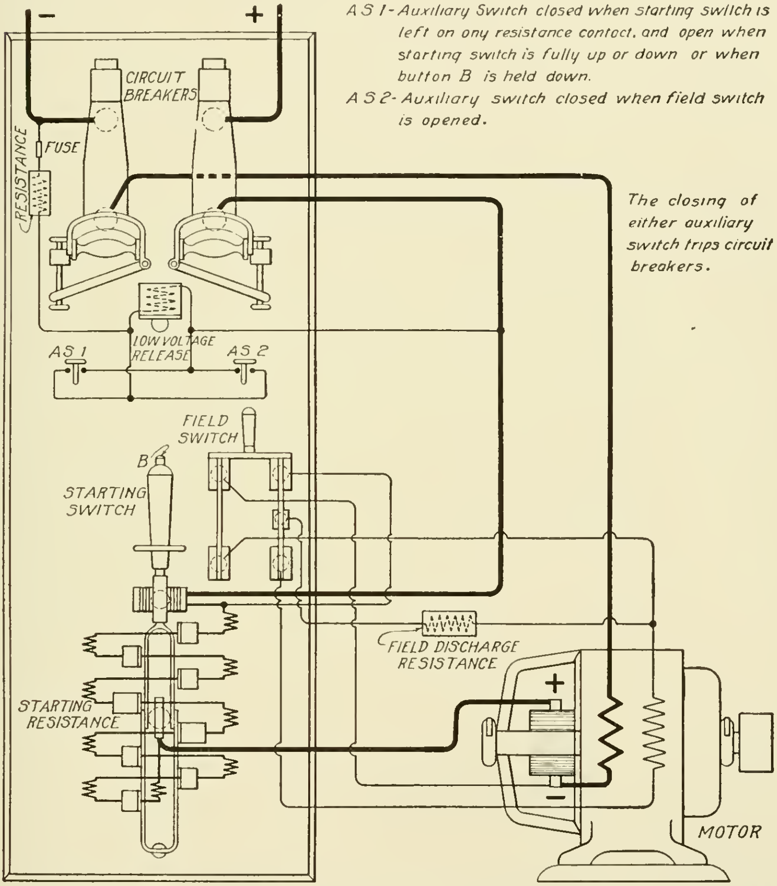


Fig. 9. Wiring Diagram for Feeder Circuits Used for Power Purposes

switch to the full "off" position, closed the field switch, and closed the circuit breaker. In order to prevent the starting switch being left in an intermediate position, a push button was placed on the end of the handle of the starting switch, which would open the circuit breaker if released at any position of the switch except the last.



AS 1 - Auxiliary Switch closed when starting switch is left on any resistance contact, and open when starting switch is fully up or down or when button B is held down.

AS 2 - Auxiliary switch closed when field switch is opened.

The closing of either auxiliary switch trips circuit breakers.

Fig. 10. Layout for "Fool Proof" Switchboard Panel for Motor Equipment in Large Mill
Courtesy of General Electric Company

It is impossible, with this panel, to do anything which would cause trouble or injure the motor or the starting equipment.

Arrangement of Boards. There is but little chance for variety in the arrangement of the apparatus on direct-current power switchboards. The carbon break circuit breakers always used should be mounted at the top of the panels, where any arc blown up from the contacts when the breaker opens will do no harm. Instruments are logically placed just below the circuit breakers because that location brings them at about the right height to be conveniently observed. Rheostat handwheels and potential receptacles are usually placed next, and the lever switches below them. In cases where watt-hour meters are used, they may be placed on the subbases. Fig. 11 shows a direct-current switchboard, consisting of generator panels and feeder panels, a voltmeter being mounted on a bracket at one end. The equipment is simply and logically arranged, and the board presents a neat and symmetrical appearance. Fig. 12 shows a back view of the same board, and shows how the buses and connections are arranged.

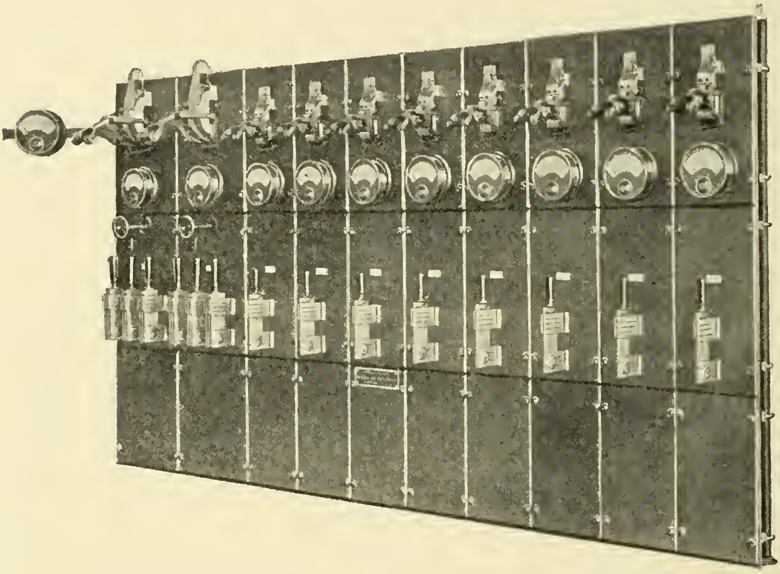


Fig. 11. Direct-Current Switchboard with Generator and Feeder Panels
Courtesy of General Electric Company

LIGHTING BOARDS

Voltage. In plants whose load is principally or in part lighting, the voltage is limited. While lamps can be obtained for 220 or 250 volts, the most economical voltage is about 125 volts. There are two ways of obtaining the proper voltage: The machines may be wound to give 125 volts at the terminals, or a three-wire system may be used with 125 volts on each side of a neutral and 250 volts across the outside wires.

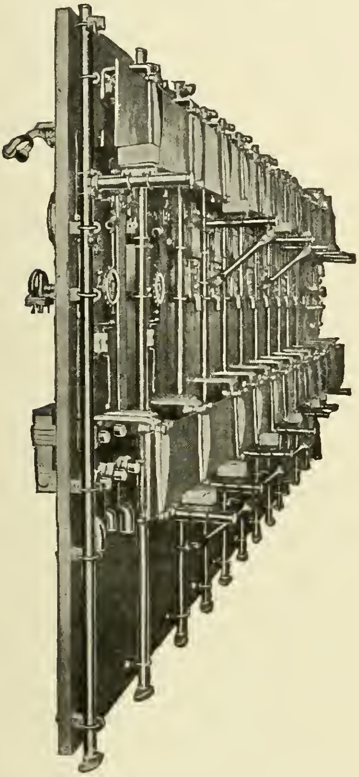


Fig. 12. Back View of Switchboard Shown in Fig. 11 Giving Location of Busbars
Courtesy of General Electric Company

Two-Wire System

Where a two-wire system is installed, the equipment is very similar to that for direct-current power. There are coming to be so many installations of small plants throughout this country, on farms and residences where central station service is not available, that a great demand has arisen for panels that are extremely simple and cheap.

Equipment for Small Board. The minimum equipment possible is:

1 Lamp
1 Lever switch (fused)

The lamp will be used for voltage adjustment by means of the field rheostat which will probably be mounted on the wall. The switch furnishes a means of disconnecting the generator, and the fuses give the necessary protection.

A little better panel is obtained by substituting a voltmeter for the lamp and arranging the panel supports so that the field rheostat can be mounted directly below the panel. An ammeter can also be added to improve the equipment still further. The equipment can be still further improved by using supports to carry the panel on the floor and mounting the rheostat back of the panel. A panel similar to this but with two separate feeder circuits is shown in Fig. 13, with the wiring diagram in Fig. 14. Such panels carrying

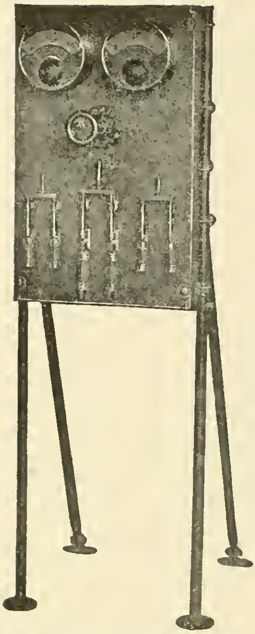


Fig. 13. Two-Wire Lighting Board with Separate Feeder Circuits

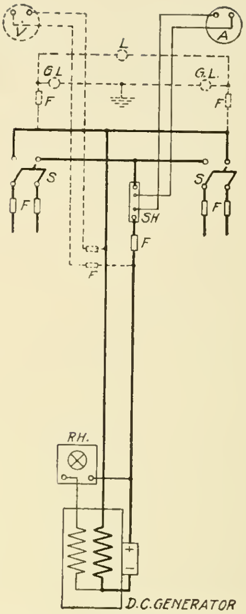


Fig. 14. Wiring Diagram for Fig. 13

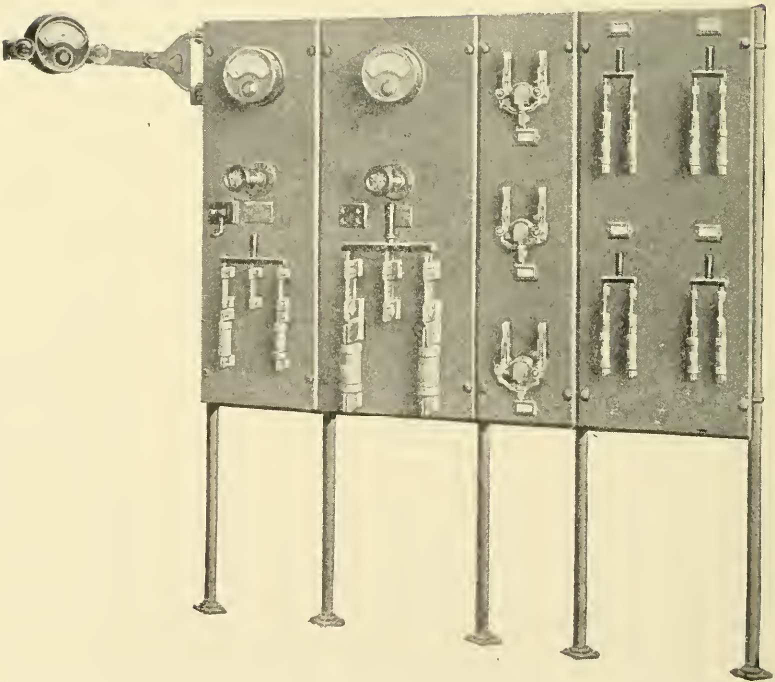


Fig. 15. Two-Wire Lighting Board with Three-Pole Switch for Compound Wound Generators Operating in Parallel

Courtesy of General Electric Company

both the generator and feeder equipments can be built where the plant contains only one generator and up to about six feeders. After that, the generator and feeder equipment are mounted on separate panels. The generators are also equipped with a three-pole switch when compound wound and operated in parallel. Only the outside poles need be fused. Such panels can be bought from any manufacturer at very moderate prices, and the equipment is all that is required for the smaller plants. See Fig. 15.

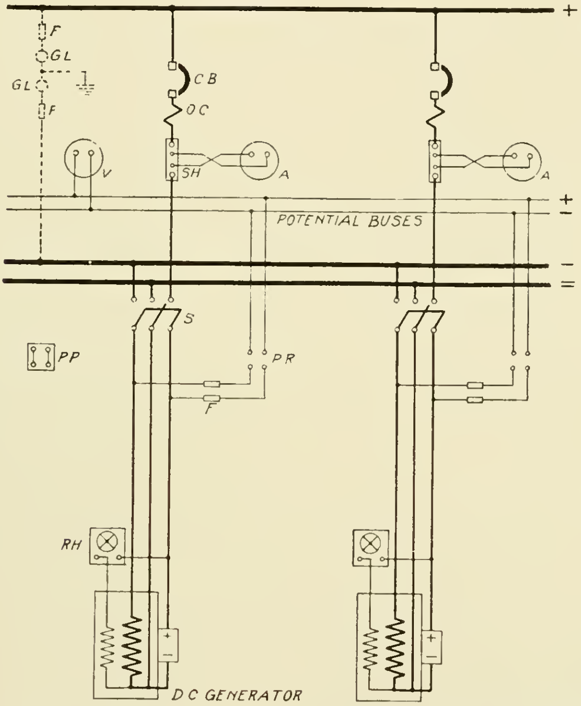


Fig. 16. Wiring Diagram for Large Lighting Board with Circuit Breakers

Equipment for Larger Board. In larger plants, where several generators of considerable size may be installed, a better equipment is considered necessary. This is true, first, because greater reliability is necessary where the apparatus protected represents a large investment, and second, because the switchboard in a large plant will be a smaller proportion of the total investment, and can therefore in itself be of higher grade. The wiring diagram for such a board is shown in Fig. 16.

Large generators are usually equipped with:

1 Single-pole circuit breaker
1 Ammeter
1 Voltmeter (for all generators)
2 or 3 single-pole switches, or 1 triple-pole switch

For 125-volt machines, the ampere capacity often is so high that a triple-pole switch can not be used in any case because it would be too hard to operate all three poles together. The large current carried also makes it necessary to use great care in laying out the connections back of the panels, so that proper clearances can be obtained and so that the backs of the panels will be as clean as possible. One should never be misled into believing that sufficient space has been allowed for the apparatus when the front of the panel shows sufficient clearances. It is more often necessary to figure closely because of large connections than because of large apparatus on the front of the panel, and crowding back of the panel is apt to cause more trouble than in front. The arrangement of the apparatus on these panels is not different from that on the power boards.

Three-Wire System

If a three-wire system is to be installed, the circuits become a little more complicated. The voltages in this case, namely, 125 and 250 volts, may be obtained in two ways, each of which requires different switching equipment.

Equipment for Two Generators in Series. If two 125-volt machines are operated in series to give 250 volts across the lines, and the neutral is tapped between the two machines, then the equipment is as follows:

2 Overload circuit breakers
2 Ammeters
2 Rheostat mechanisms
2 Double-pole lever switches
1 6-point potential receptacle with 4-point plug

The circuit breakers are connected, one between the armature and neutral bus on each machine. One of these circuit breakers opening will disconnect its machine from the circuit, but leave the other machine still supplying current to the system. This is right if the neutral wire is made large enough to carry the same current as the outside wire. If the neutral wire is smaller, there is danger of burning it up, and then the two circuit breakers should be interlocked so that the opening of one will cause the other to open also. Two ammeters are necessary, since the current supplied to the two outside wires varies according to the amount in the neutral. One pole of each of the switches is in the main lead from the generator to the bus, and the other is in the equalizing lead. The potential receptacle is connected so as to read the voltage of either machine.

Equipment for Three-Wire Generator. If a three-wire machine is used, the equipment is similar, but is connected a little differently. In this machine, the neutral is derived by means of a transformer or compensator connected to the armature coils through collector rings. Switches are placed either between these collector rings and the compensator, or between the neutral point of the compensator and the neutral bus. Since the latter takes only one single-pole switch, where the former takes one or even two double-pole switches, it seems best to use it. The compensator can always be disconnected at the machine by lifting the brushes.

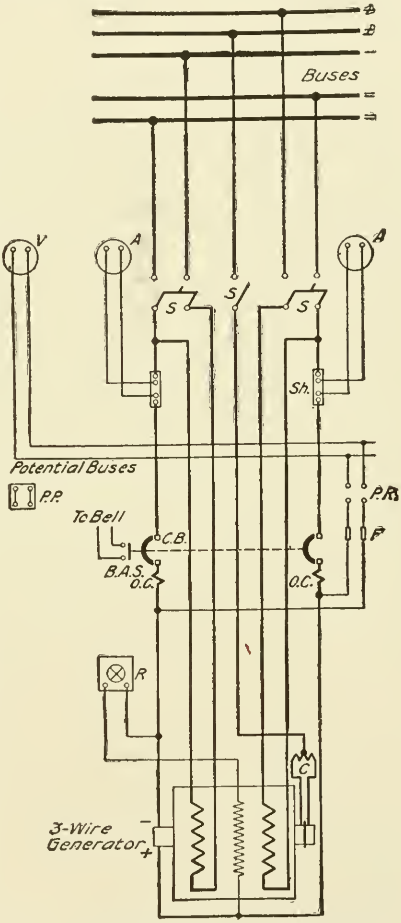


Fig. 17. Wiring Diagram for Three-Wire Generator Switchboard Equipment

Circuit Breakers. The circuit breakers can not be connected in these machines as for two machines in series, but must be on the two sides of the armature. These machines have two series fields when compound wound, and therefore two equalizer switches the same as two machines in series. Two ammeters are necessary, as in the previous case, but only one rheostat mechanism, and a four-point potential receptacle instead of a six-point.

Fig. 17 shows one of several schemes that have been devised for three-wire machines, while Fig. 18 is the same scheme simplified for purposes of description.

It will be seen from these diagrams that the circuit breakers are connected between the armature and the series fields. They are also interlocked, so that the opening of one will open the other, and thus protect the compensator and neutral. The circuit breakers must necessarily be connected as shown, in order to have the armature current trip them. If they were connected between the series fields and the buses, they might have more or less than the armature current, depending on the direction of flow of the equalizing current. The connection shown also allows the series fields to be connected in circuit before the machine is paralleled with another. This allows the operator to adjust the voltage to more nearly the proper value (including the compounding effect of the series field), and therefore causes less voltage disturbances than a scheme where only armature voltage is read before closing the switches.

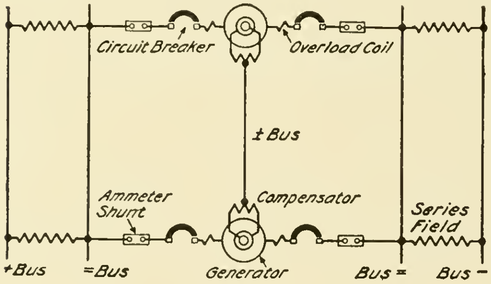


Fig. 18. Simplified Wiring Diagram for Fig. 17

Compensators. Machines are generally designed with a compensator to take care of twenty-five per cent unbalancing, and usually there is no likelihood of any amount in excess of this. In cases where exceptionally heavy unbalancing may occur, an overload relay can be placed in the neutral lead and arranged to trip the main circuit breakers. An overload circuit breaker should never be used, since opening the neutral alone might do serious damage to lamps or other apparatus connected to the circuits.

Protection for Feeder Circuits. Three-wire feeder circuits may be protected by three-pole fused lever switches, and where the load is all lighting with few violent fluctuations or short circuits, such equipment is the cheapest and is satisfactory. If load fluctuations are severe or short circuits are frequent, circuit breakers should always be used because of the saving in fuse replacements and because of the time saved in getting a circuit into service after trouble has occurred. For power circuits taken from the outside buses, circuit breakers are nearly always used. If the neutral circuit is grounded, such breakers should always be double-pole, double-coil. If a single-coil breaker were used, a ground might occur on the wire without any overload coil, and the feeder would be unprotected. Double-pole double-coil breakers are usually considered sufficient for three-wire feeders, especially where the neutral is grounded, and

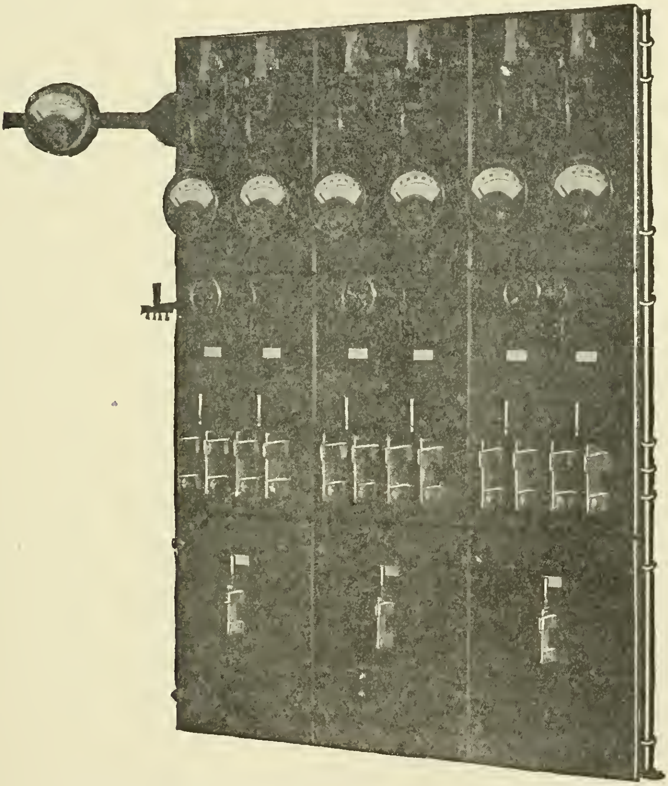


Fig. 19. Front View of Three-Wire Power and Lighting Switchboard
Courtesy of General Electric Company

it is not necessary to open the neutral circuit to the feeders. For two-wire feeders between the neutral and outside, or for two-wire feeders between outside wires, if the neutral is not grounded, a double-pole single-coil breaker is sufficient.

If ammeters are wanted for feeders, two are necessary for each three-wire feeder, and one for each two-wire feeder.

Arrangement of Three-Wire Boards. The arrangement of the equipment for three-wire switchboards follows in general the same lines as the two-wire power and lighting boards. The difference in connections sometimes requires some modification on the back of the board, but the front is only different in the apparatus there mounted. On very large equipments, the expense for cable is very high, and in such cases or where the switchboard is very far from the machines controlled, the generator breakers are often mounted on separate panels near the machines. This leaves only two main cables and a neutral cable to bring to the board, and the saving thus effected will more than offset the cost of making the circuit breakers electrically operated so they can be controlled from the switchboard. Another advantage is that the board is relieved of some very heavy apparatus, and the back is simplified, and the connections reduced.

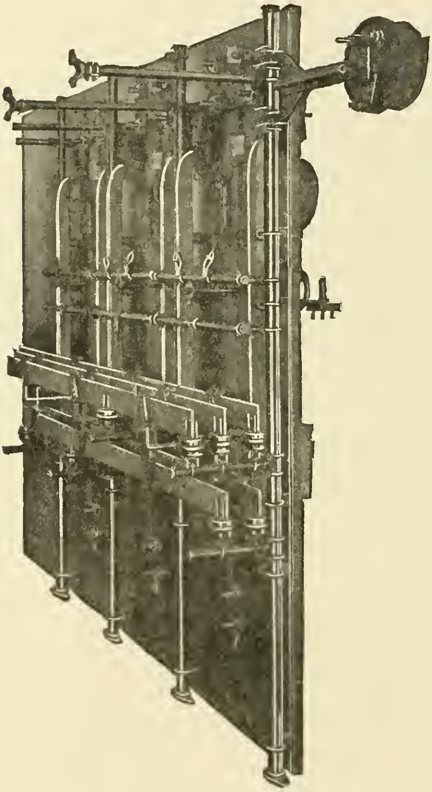


Fig. 20. Rear View of Switchboard Shown in Fig. 19
Courtesy of General Electric Company

Figs. 19 and 20 show the front and back views of a three-wire switchboard. The panels shown control only the generators. Fig. 21 shows a three-wire feeder board using lever switches.

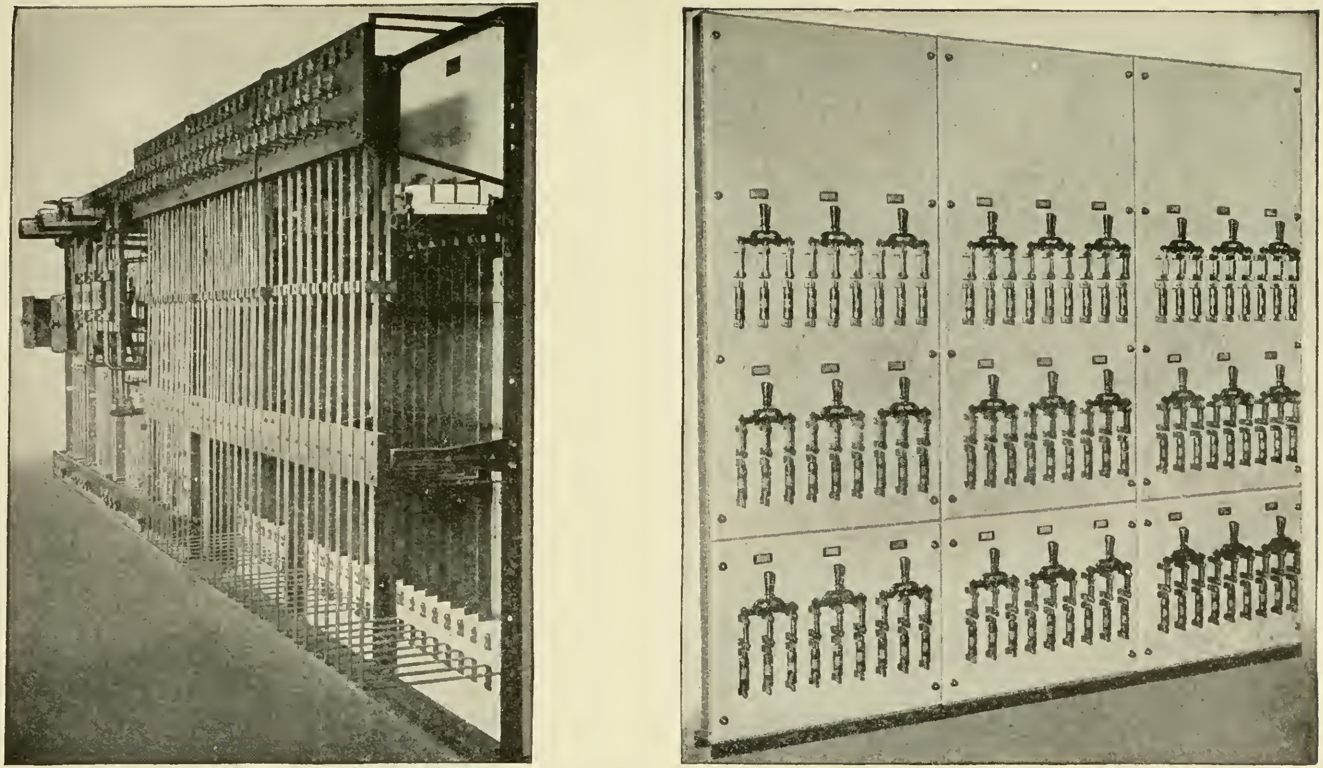


Fig. 21. Front and Back Views of Westinghouse Three-Wire Feeder Switchboard
Courtesy of Westinghouse Electric and Manufacturing Company

Switchboard Equipment for Rotary Converters. Rotary converters are coming largely into use for lighting service in the larger cities, especially since the introduction of the regulating pole and synchronous booster rotary converters. They may be useful for either two-wire or three-wire service. In the latter case, the neutral is obtained from the transformers supplying the converter.

The switchboard equipment for the direct-current end of these machines is quite similar to that for direct-current generators and is mounted in the same way on the panels. If the converter is equipped with regulating poles or a synchronous booster, there are some slight changes to take care of the difference between these and standard machines.

MINING SWITCHBOARDS

Requirements. The use of electric current in mines differs somewhat from other uses because of the conditions. In the first place, current is generally used for operating locomotives, which means that the negative is grounded. In the second place, the conditions underground are very bad, and not only is it impossible to keep the circuits out of reach of the men, but trouble is frequent due to grounds on the positive, which are really short circuits, since the negative is already grounded. These conditions almost always limit the voltage to 250 or 275 volts. There is a third condition which also affects the switchboard, and that is, the tendency to get the cheapest and simplest equipment possible. There are a number of reasons for this, as for example, the fact that such equipment in a mining plant is apt to have a rather short life. Thus, by putting in a cheap equipment, the amount of depreciation to be charged off each year is kept at a minimum. The idea of keeping the installation simple implies in itself good engineering, especially in such plants where the men handling the equipment are not usually trained or experienced in electrical work.

Generator Equipment. Generator equipments for this service usually consist of:

1 Single-pole circuit breaker
1 Ammeter
1 Voltmeter (used for all machines)
1 Rheostat mechanism
1 Single-pole main switch

Station lighting switches (single-pole double-throw) are sometimes added to this equipment. Remembering that the system is grounded, it will be seen that it would not be safe to connect the switch and circuit breaker in series on the positive side. Since one side is already grounded, the chances of a ground which would cause trouble are very much increased. If such a ground should occur between the machine and the switchboard, there would be nothing to protect the machine. In order to overcome this, the circuit breaker is connected between the negative brush of the generator and the series field. Thus, protection is obtained equal to that on the two-wire ungrounded switchboard described previously. Fig. 22 shows the wiring diagram of a 275-volt mining generator panel with the circuits arranged as described.

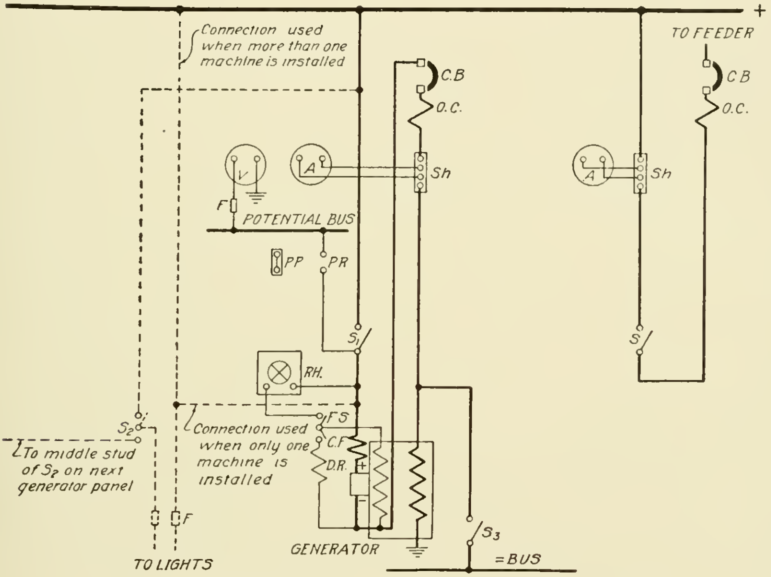

+
Connection used when more than one machine is installed
TO FEEDER
C.B
O.C.
C.B
O.C.
V
A
Sh
A
Sh
F
POTENTIAL BUS
PP
PR
S_1
S
RH.
FS
C.F.
D.R.
Connection used when only one machine is installed
S_2
To middle stud of S_2 on next generator panel
F
TO LIGHTS
GENERATOR
S_3
=BUS

Fig. 22. Wiring Diagram for a 275-Volt Mining Generator Panel

Feeder Circuits. Feeder circuits for mining plants are usually equipped with a circuit breaker and a lever switch in series with an ammeter when desired.

Arrangement of Apparatus. The arrangement of the apparatus is in every way similar to other direct-current switchboards. Quite often, smaller panels without sub-bases are used in such plants, and while such panels do not present a very pleasing appearance, they make a compact outfit, which serves every purpose for which it is intended.

RAILWAY SWITCHBOARDS

Up to within the last few years, railway switchboards could have been considered under a single classification. However, since the advent of the high voltage direct-current railway, there have been a number of changes necessary in the switching equipment, and the low voltage and high voltage boards will bear separate discussion.

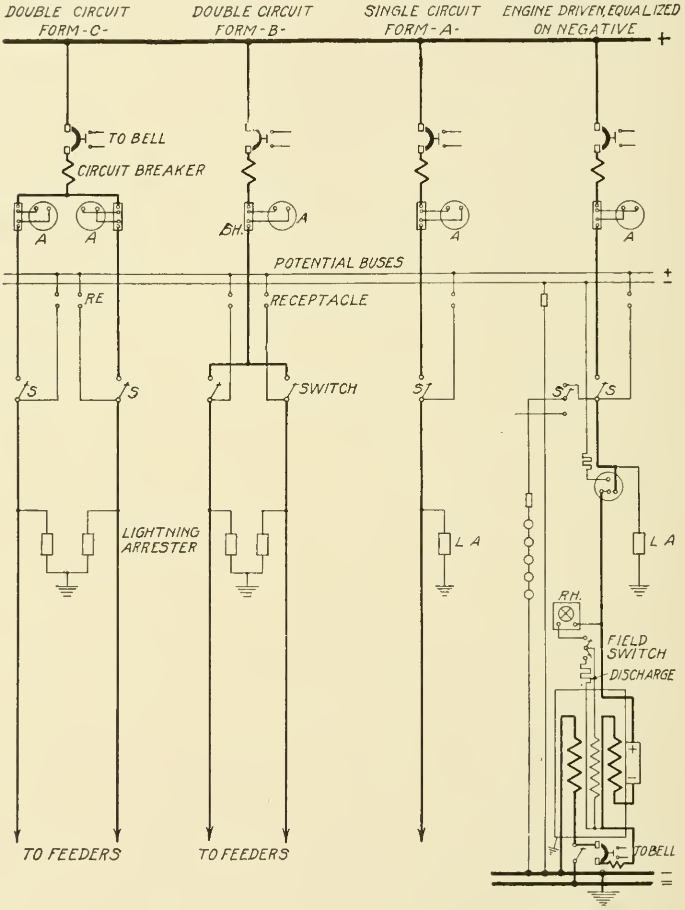


Fig. 23. Wiring Diagram for Railway Switchboard with D. C. Feeder Circuits

Low Voltage Work

In the low voltage railway work, 600 volts only are considered. Practically all railways operate with a grounded negative, and such a condition is always assumed when discussing such work.

Generator Equipment. *Steam-Driven.* Railway generators are as a rule equalized on the negative side with the series field connected directly to the ground. If the generator is steam-driven, there is considerable danger of damage in case the machine becomes short-circuited by the positive brushes or the cable to the switchboard becoming grounded. (See "Motor-Driven" arrangement.) Because of this possibility, the best equipment will always include a negative circuit breaker, Fig. 23. The necessary switchboard apparatus for a steam-driven railway generator is therefore as follows:

1 Single-pole circuit breaker (positive)
1 Ammeter
1 Rheostat mechanism
1 2-point potential receptacle and 2-point plug
1 Single-pole lever switch
1 Watt-hour meter (optional)
1 Single-pole circuit breaker (negative)
1 Equalizing lever switch

The latter two are usually mounted near the machine in order to save running cable to the switchboard. The voltmeter is usually mounted on a bracket, one instrument being used for the whole board. In some cases, small lighting switches are added to the generator panels to take care of station lighting from the 600-volt bus.

Motor-Driven. If the generator is driven by a motor, the above equipment can be modified to the extent of omitting the negative circuit breaker. Damage can not so easily result in this case, since a short circuit would cause the motor circuit breaker to open if the positive breaker on the generator would not take care of it. This, of course, would kill the voltage and the machine would not be damaged.

Rotary Converter Equipment. Rotary converters are used a great deal in railway systems. The panels for their control are very similar to those for motor-driven generators. A low voltage release or shunt trip attachment is generally added to the circuit breaker to be actuated by the speed limit device on the machine, so that excessive speed trips the circuit breaker. This is done so that the machine can not be driven at high speed as a motor from the direct-current bus if the alternating-current source should fail.

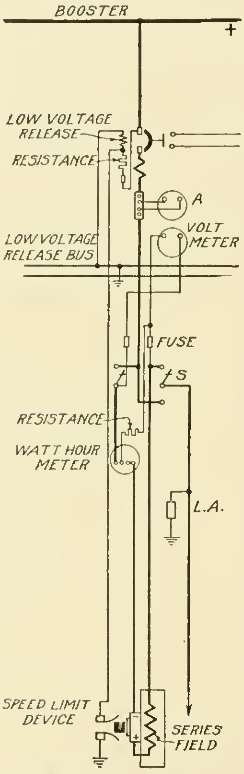


Fig. 24. Wiring Diagram for Series Booster Used in a Railway Feeder

Feeder Circuit Equipment. Railway feeder circuits are equipped with:

1 Circuit breaker
1 Ammeter
1 Single-pole lever switch
1 2-point potential receptacle, for reading the trolley voltage before connecting in the feeder

The equipment may be modified at times, as for instance, putting two circuits on one panel and having a common circuit breaker for the two, or a common ammeter for the two, or both a common ammeter and circuit breaker.

Booster Equipment. Boosters are also used to some extent in railway systems for boosting the trolley voltage. The standard equipment for such a machine is:

1 Single-pole circuit breaker with low voltage release
1 Ammeter
1 Voltmeter
1 Single-pole single-throw lever switch
1 Single-pole double-throw lever switch
1 Watt-hour meter (optional)

The connections are such that the feeder can be operated either with or without the booster in circuit. The speed limit device on the machine is usually connected to the low voltage release, so that excessive speed trips the circuit breaker, and disconnects the machine. Fig. 24 shows the wiring of a series booster used in a railway feeder.

High Voltage Work

Requirements Due to Voltage. In recent years, direct-current railways have adopted high voltages a great deal. There are in operation and building in this country, several roads using voltages up to 2400 volts. Such voltages naturally cause some radical changes in the switching equipment in order to make it safe to handle. When the first 1200-volt railways were built, the panels for controlling the generators and feeders were built very much the same as had been the practice for 600 volts. The only differences were that all parts were a little better insulated; the lever switches were supplied with longer handles and with shields to prevent the operator coming into contact with the switch blades; the instruments were better insulated; and the circuit breakers were supplied with longer handles. However, as the use of such voltages and higher became common, engineers demanded something better for the switchboard. Several manufacturers are now supplying equipments which meet most conditions very well.

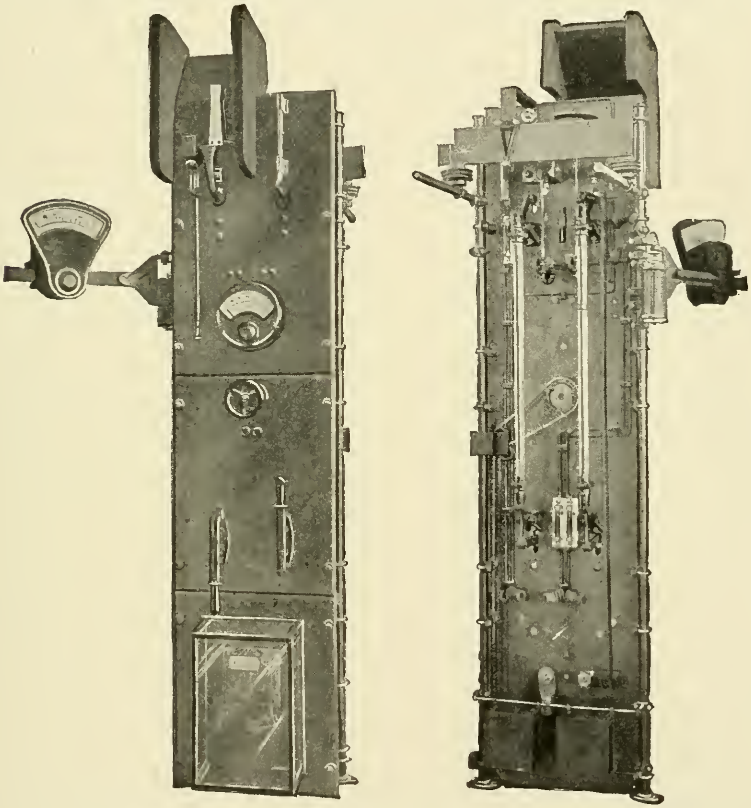


Fig. 25. Front and Rear Views of Panels for 1200-Volt Direct-Current Railway Switchboard
Courtesy of General Electric Company

Fig. 25 gives the front and rear views of a panel, in which the live parts have been mounted out of reach of the operator. The switch and circuit breaker are mounted at the top of a tall panel and are operated by means of handles at the bottom of the panel. The connecting rods in the mechanisms back of the panel are made of treated wood. These wooden rods act as insulators between the handles and the devices themselves. The ammeter is enclosed in a moulded insulating cover, all receptacles are set well down into porcelain bushings out of reach, and the watt-hour meter is fitted with a cover which does not touch the live parts. Even the low voltage release and "reset" for the bell alarm switch are operated through insulating rods. The whole equipment can be operated with as great safety as a 600-volt equipment. In the panel shown, it will be seen that an arc chute has been built around the upper part of the circuit breaker to direct the arc and prevent its being communicated to the connections at the back or to the frame.

Generator Equipment. *Two Machines in Series.* Since the voltage used is obtained in two ways, either by winding the machines for the high voltage direct or by operating two machines in series, the switchboard equipment varies somewhat. For two generators connected in series, the equipment is as follows:

1 Single-pole circuit breaker
1 Ammeter
1 Double rheostat mechanism (one for each machine)
2 2-point potential receptacles
1 Single-pole lever switch
1 Watt-hour meter (optional)
1 Voltmeter (common to all machines)

In some cases where both 600- and 1200-volt cars are operated, it is necessary to install a panel for each of the machines. If the machines are always to bear the same relation, then the panel for the low machine may have 600-volt equipment.

High Voltage Single Machines. Where machines are wound directly for the voltage used, only one rheostat mechanism and one potential receptacle are required.

Converter Equipment. Rotary converters are equipped as for low voltage, but use the high voltage devices similar to those described above.

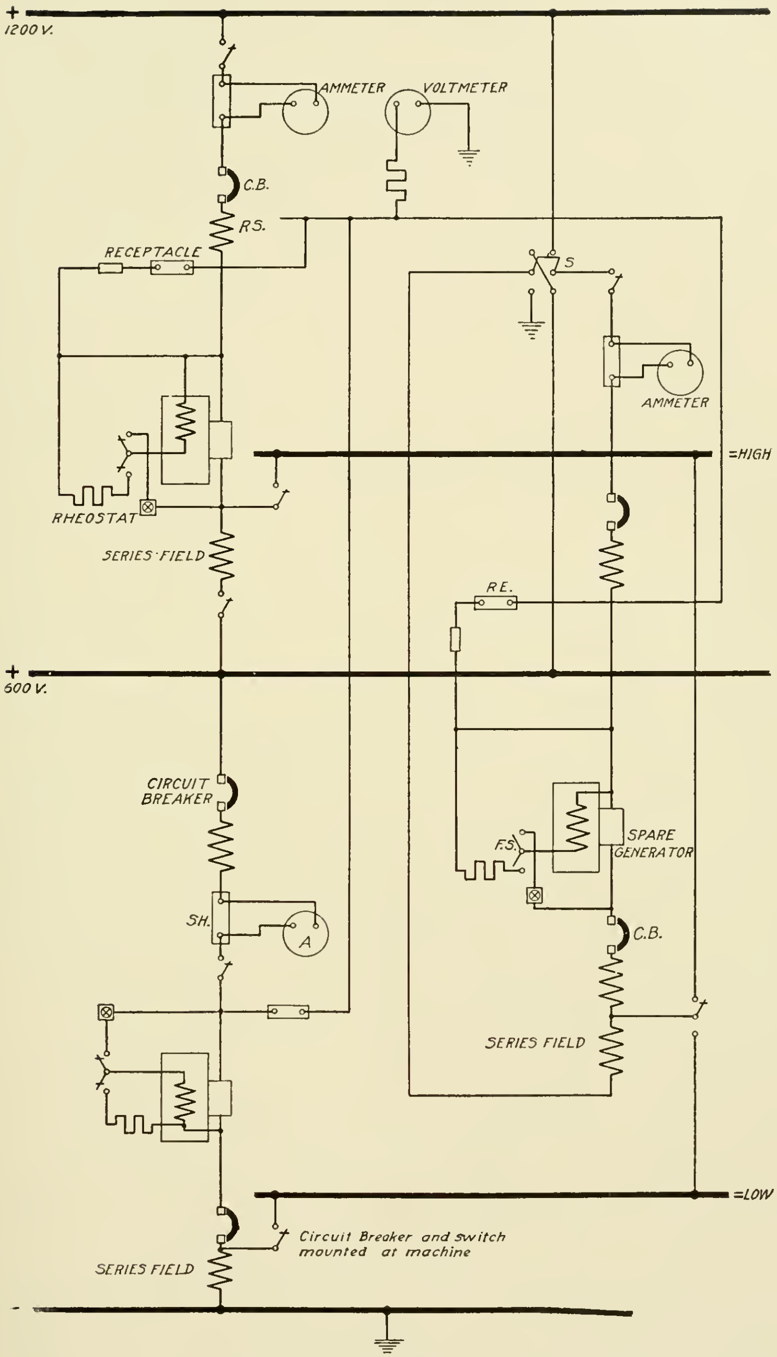


Fig. 26. Wiring Diagram for Switchboard Equipment of a Station Supplying 600-Volt and 1200-Volt Trolleys with One Spare Generator

Feeder Equipment. Feeders are always equipped as for lower voltages, but with the apparatus for the higher voltage.

A number of complications and modifications are encountered on systems where both 600- and 1200-volt service is required. This is especially true when the station is equipped as shown in Fig. 26. This shows the wiring for a station supplying both 600-volt and 1200-volt trolleys and containing one spare generator which is arranged to be used in place of either of the other machines.

Extra High Voltage. Where the voltage used is as high as 2400 volts, the equipment is similar to that for 1200 volts, but greater care is necessary to insure proper insulation. All live parts in such a panel are run through porcelain bushings, since even marble can hardly be depended upon at that voltage.

BATTERY SWITCHBOARDS

In order to do justice to the subject of battery switchboards in all its phases, a great deal more space would be required than is available here. However, the use of the battery in central stations and in private plants has become so common that something should be said on the subject of its control.

Switch=Operating Equipment. The most common use of the battery in a central station, outside of its uses as an auxiliary source of power, is for operating the switches or other electrically-operated devices. In this service, the load on the battery normally is very slight, but may be very high for short periods. The cells are usually charged from a small motor generator set so that the voltage applied may be regulated independently. In this case, the equipment becomes very simple.

The generator of the set is equipped with:

1 Ammeter
1 Circuit breaker (positive)
1 Single-pole lever switch (negative)

The battery is equipped with:

1 Ammeter
1 Single-pole single-throw lever switch
2 Single-pole double-throw lever switch

A voltmeter is supplied arranged so that it can be connected across the generator, across the end cells, or across a single pilot cell. The connections are shown in Fig. 27.

It will be seen from the connections that normally the generator is connected across the whole battery, and the battery is in turn connected across the discharge buses. When the charge is started, the battery is divided, and approximately five-sixths of it is connected to the discharge bus, while the generator is still connected across the whole battery. Thus raising the generator voltage for the charging operation still leaves only about normal voltage on the discharge bus. As the voltage of the battery rises during charge, the generator is thrown on to the main part only to give it the final charge. After the charging is completed, the switches can be placed

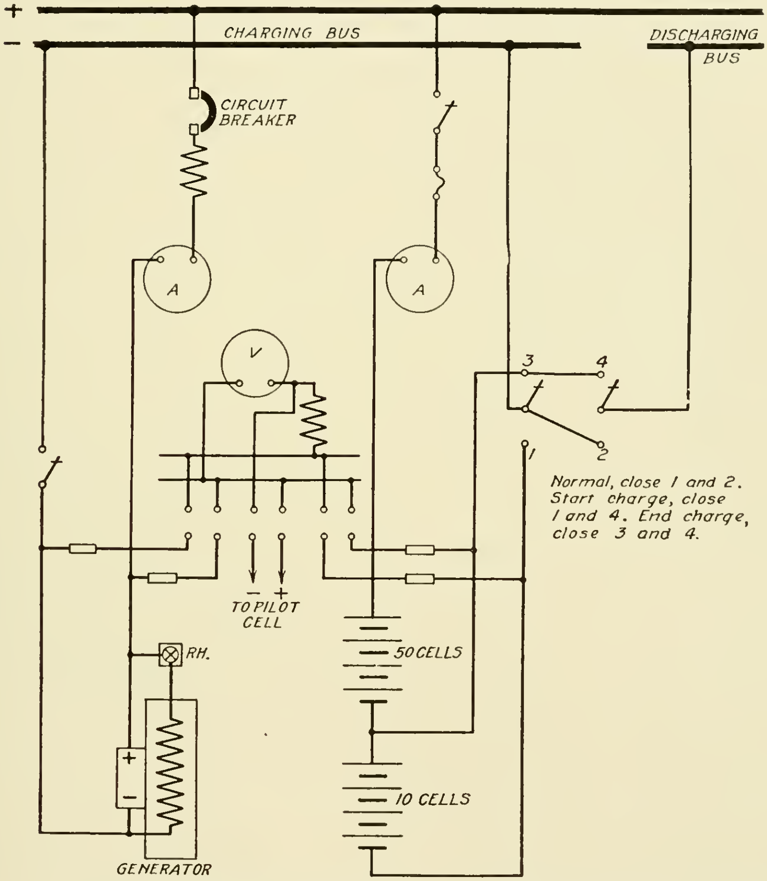


Fig. 27. Battery Switchboard Wiring Diagram for Operating Switches and Other Devices

in the normal position and the generator operates with the battery floating across its terminals.

The above scheme can be modified to charge from a constant potential source by the insertion of a charging resistance. The source of potential must, of course, be high enough to give full charge to the cells.

Equipment for Isolated Plants. The use of batteries in connection with isolated lighting plants on farms and in residences leads into a field which is somewhat different. In such plants, the first requisite is that the switchboard be so simple that a person with no electrical knowledge can operate it with only a few instructions. In addition, the apparatus must be protected so that there is little chance of its being injured.

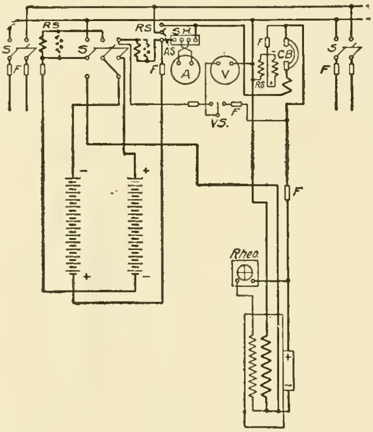


Fig. 28. Wiring Diagram for Combined Generator, Battery, and Feeder Panel for Isolated Plant

Fig. 28 shows the wiring diagram of a combined generator, battery, and feeder panel, designed for such service. It will be seen that all adjustable resistances or other complications have been eliminated and the equipment reduced as far as is consistent with the protection necessary.

The equipment consists of:

1 Single-pole reverse current and low voltage circuit breaker
1 Ammeter
1 Voltmeter
1 Voltmeter switch
1 Ammeter switch
1 Triple-pole double-throw lever switch
2 Double-pole fused circuit switches
1 Rheostat mounting

Arrangements for Charging and Discharging. The method of charging here shown provides for connecting the two halves of the battery in multiple with a suitable resistance in series. This allows the generator to be used on the circuits during charging so that continuous service may be given.

Referring to Fig. 28, it will be seen that, when the triple-pole switch is up, the battery is connected with the two halves in multiple across the generator and also across the buses. A fixed resistance is connected in each leg of the battery to reduce the voltage across the cells to the proper amount. This fixed resistance is used in order to simplify the equipment, and while the charging rate can not be adjusted, as is done on larger installations, the results obtainable are satisfactory for such an installation. The simplicity is the thing that makes this equipment valuable. The whole operation of charging consists simply in throwing the triple-pole main switch to the upper position.

For discharging, the triple-pole switch is thrown down and the two sets of cells are connected in series and will discharge to the buses.

During the charging operation, the current going into the battery can be read by throwing the ammeter switch up. When this switch is down, the instrument reads the total current being supplied by the generator.

During discharge, if the generator is still running its current can be read by throwing the ammeter switch down. Also, the current being supplied by the battery can be read by throwing the switch up.

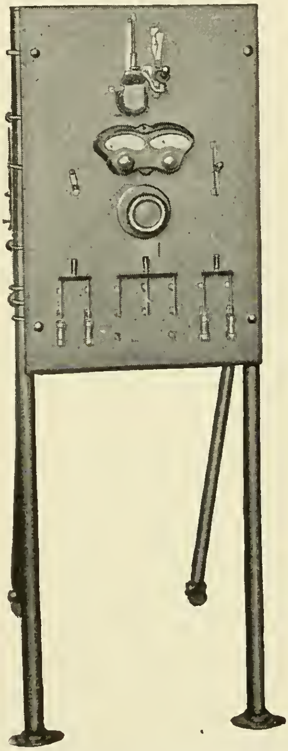


Fig. 29. Switchboard for Equipment Shown in Fig. 28
Courtesy of General Electric Company

The voltmeter switch throws the voltmeter across the cells in one section of the battery (during the charging operation) or across the generator. During discharge, of course, the battery voltage is the same as the generator voltage, so that only one reading is necessary.

Fig. 29 shows the front view of such a panel and illustrates clearly how simple an equipment it makes. These panels can be varied considerably for different conditions or different methods of operation, but simplicity and ease of operation should always rule in laying out such an equipment.

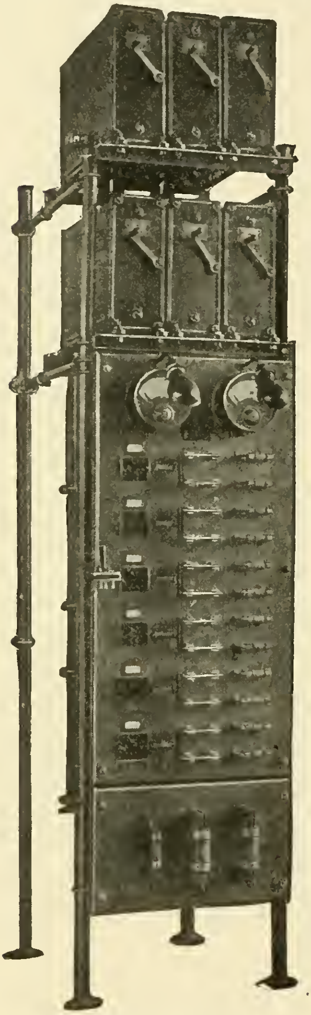


Fig. 30. Electric Vehicle Charging Equipment
Courtesy of General Electric Company

Electric Vehicle Charging Equipment. With the increased use of electrically-driven vehicles, both for pleasure and for general hauling, the charging switchboard becomes more and more important. For this service, it is usually required that a panel be furnished from which several cars can be charged at one time, and which will permit of both current and voltage readings on any car. In order to make proper adjustment of the charging current, it is most convenient to have the charging rheostats mounted in connection with the panels. A very convenient arrangement recommended by some of the manufacturers of electric vehicles is shown in Fig. 30. The equipment here consists of:

1 Ammeter
1 Voltmeter
1 Potential receptacle for main line voltage
1 Potential receptacle for each charging circuit
1 Double-pole double-throw lever switch for each charging circuit, with fuses
1 Set of fuses, for the main service leads
1 Fuse in series with the ammeter
1 Set of supports for each charging rheostat

The switches are arranged so that one throw connects the battery through fuses to the buses, while the other throw also puts the ammeter in circuit. Thus the current can be read for each circuit. The potential receptacles are connected to read the actual battery voltage outside the rheostat.

Several of these panels can be installed together to take care of a large number of cars, and the circuits are conveniently arranged to run to the various charging plugs in the garage. The leads are all carried to the top of the panel, through the rheostats, and thence to the charging stations where attachment plugs are located.

ALTERNATING=CURRENT SWITCHBOARDS

Switchboards for alternating current may be divided according to the kind of service, very much as has been done for direct current; but before taking up the various divisions, it will be well to consider the reasons for the differences between the two.

Comparison of Alternating=Current vs. Direct=Current Requirements. *Separate Exciting.* Alternating-current generators are always excited from a separate source of direct current, so that a switch will always be necessary for disconnecting the field circuit from this source of power, and the ammeter may be used to read the amount of current supplied to the field at any time.

Phase Differences. In studying alternating currents, we learn that the current and voltage of a circuit may be out of phase with each other, and that the product of the two does not, in such a circuit, represent the true power. In order to read the true power being expended in a circuit, we must use a wattmeter which automatically takes care of all phase difference and gives the actual watts. A similar instrument can be so connected in circuit that it will read the part which does not represent true power, and the two can be used to advantage in many places. This latter instrument is called a wattless component indicator. Another instrument, which is sometimes used instead of the wattless component indicator, is the power factor indicator. This instrument reads in per cent the ratio of true power to apparent power.

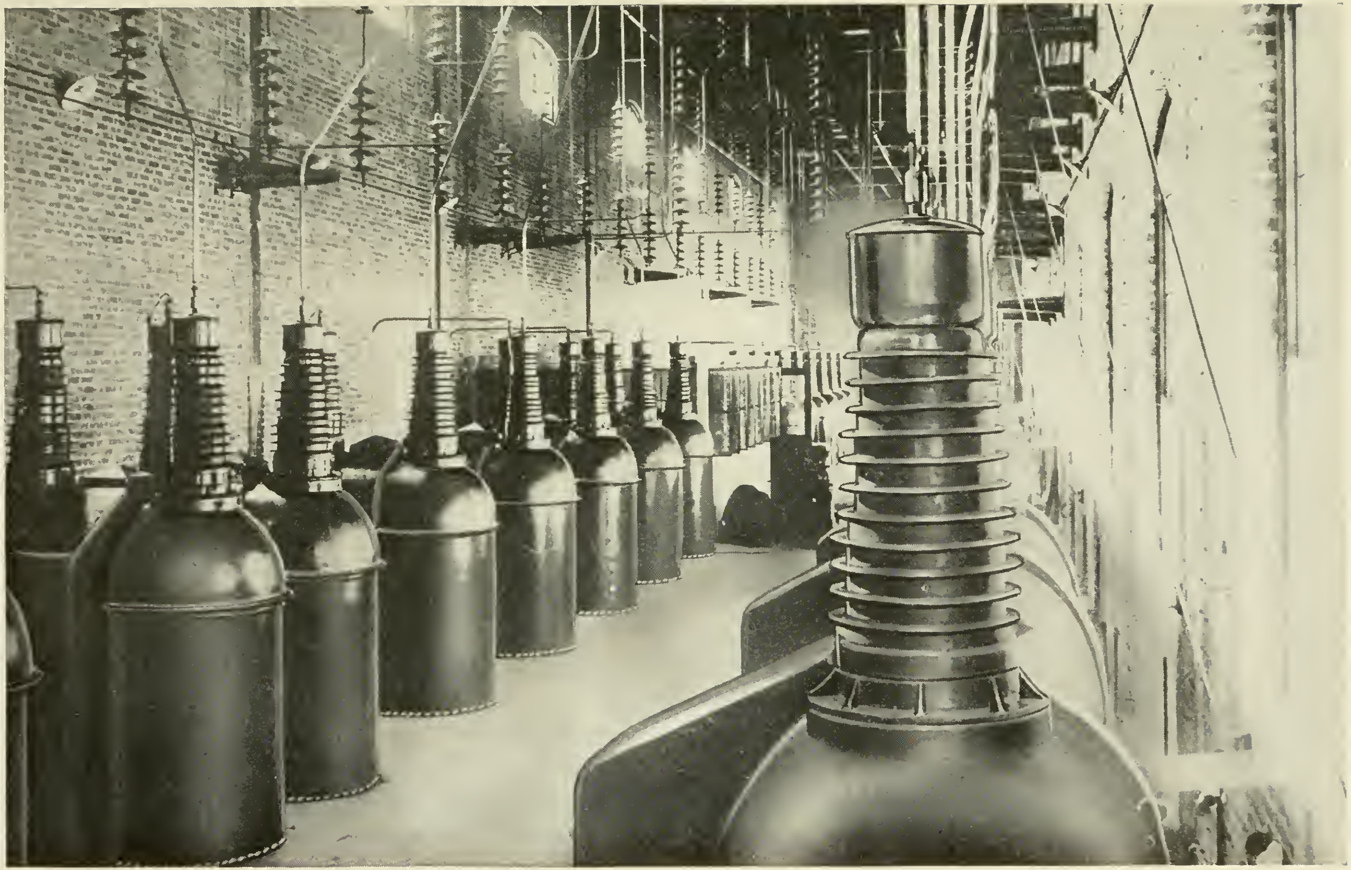
Frequency. Frequency indicators are also often required when it is necessary to keep the frequency within certain limits. It gives a check on the speed of the prime movers, and should be included in the equipment of every central station of any size. It is sometimes mounted at the machines and, in such cases, need not be duplicated at the switchboard.

Synchronism. In nearly all stations where alternating-current machines are operated in parallel, a synchronism indicator is included.

Paralleling Alternating-Current Machines. It must be remembered that the paralleling of two alternating-current machines involves more than mere voltage adjustment. The machines must be operating at the same frequency, and the voltage of each must be exactly in phase with the voltage of the other. When the synchronism indicator is properly connected to two machines, it shows whether the incoming machine is running too fast or too slow, and the speed of the pointer gives an idea as to the amount of the difference. Finally it indicates when the two are exactly in phase.

The operation of paralleling two generators then becomes somewhat as follows: The incoming machine is brought up to speed with all switches open. The field switch is then closed, the operator having first cut all the resistance into the field circuit. As soon as the machine has built up its voltage, the operator will adjust it to the same value as read on the running machine. The plugs can now be inserted in the synchronizing receptacles, and the pointer on the instrument will begin to revolve, indicating that the incoming machine is running too fast or too slow. The speed of the machine is now adjusted until the pointer on the instrument ceases to turn or moves very slowly. When the pointer is at the top of the dial and standing still, the machines are exactly in synchronism. Theoretically the machine switch should now be closed, but since this condition is almost never reached in practice, the switch is usually closed with the pointer moving. It is better to close the switch as the pointer approaches the point of synchronism rather than as it leaves it. There is an appreciable time elapsing between the instant when the eye sees the pointer in the correct position and that in which the switch makes contact; this might be sufficient to allow the machines to become considerably out of phase.

Once having the machines running in parallel, the load should be adjusted so that each machine is carrying its proportion. In direct-current practice, this is done by moving the field rheostat and changing the voltage. However, change of field current on an alternator running in parallel with another will not do for load adjustment. The governor of the prime mover should be adjusted, and any adjustment tending to increase the speed will cause the machine to take more load. Thus, the entire load or any part of



HIGH-TENSION SWITCH ROOM OF THE YADKIN RIVER POWER COMPANY

Courtesy of General Electric Company

it may be placed on the new machine by governor adjustment. It should be remembered that shifting the field rheostat only causes cross currents to flow between machines. The rheostats should only be moved for voltage adjustment and all machines should then be adjusted in the same proportion.

SMALL INDUSTRIAL POWER SWITCHBOARDS

The constantly increasing use of alternating current in mills and factories and for all industrial purposes has created a sort of separate class of switchboards. The whole equipment in such a plant is given exceptionally hard service, and in many cases is poorly taken care of. This is especially true of smaller plants, and boards in such plants should carry as little equipment as is consistent with proper protection and necessary indications.

Voltage. The voltages generally used in industrial installations are 240, 480, or 600 volts. Such potentials allow distribution with a fair amount of safety to life in factory buildings, are of high enough value to allow of the distribution of a considerable amount of power for short distances, and do not require step-down transformers even for the smaller sizes of motors. For very large amounts of power, the copper required to carry the current efficiently is so great as to be a serious handicap to good distribution.

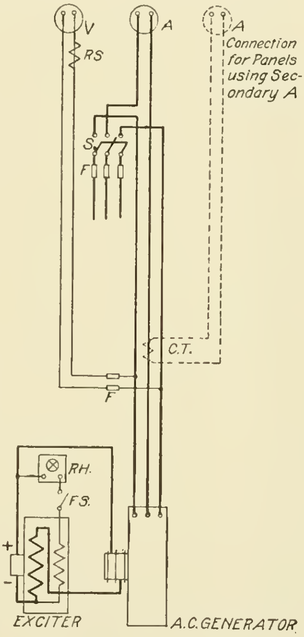


Fig. 31 Diagram for Small A. C. Industrial Power Board

Equipment for One Generator. In very small plants, where only one generator is installed, the switchboard equipment may be as simple as for direct current Fig. 31. For a generator, the following is sufficient:

1 Ammeter
1 Voltmeter
1 Rheostat mechanism
1 Field switch
1 Main switch (fused)

The switch may be of the plain lever type, up to 480 volts, and either of the quick break lever type or of the oil break type for 600 volts. If an oil switch is used, it can be made automatic, doing away with the fuses.

Such a panel gives means of obtaining the proper voltage, means of reading the load in amperes, and protection against overloads and short circuits. The feeder wires can be taken directly from the generator switch, so that for a small plant only the one panel would be required.

Feeder Circuits. Where there is but one generator installed, the National Board of Fire Underwriters allows such panels to be constructed with several fused switches all connected to feeder circuits. This means, of course, that there is no generator switch and that all the feeder switches must be opened to disconnect the generator entirely. However, since this arrangement is used for one generator only, the field switch can always be opened, which takes all the voltage off the entire system. It must be understood that this is only possible where there is but one generator supplying current to the feeders.

Where there are a large number of feeder circuits, it becomes necessary to add feeder panels, and in such cases, the generator equipment is usually mounted on a panel by itself. It may still be as simple as in the previous case, except that a separate generator switch may be added for greater convenience in operating. The one generator switch can be opened on shutting down, and the machine can be brought up to speed and voltage before the switch is closed on starting up, much more easily than with all the feeder switches.

Equipment for Two or More Generators. The above-described panels cover a wide field in small plants, but even in such plants it is often found convenient or necessary to have more than one generator. In plants where more than one machine is used, it becomes necessary to operate them in parallel, either while shifting the load from one to the other if one is only a "spare", or during longer periods if the load requires it.

Synchronism Indicator. Even in small plants, parallel operation should mean the addition of a synchronism indicator to the equipment. Machines can be synchronized by means of lamps only, but the convenience and accuracy of the operation with an indicator make the small extra investment always worth while.

Field Ammeter. There should always be at least a field ammeter in addition to the alternating-current ammeter, for each of the generators. This instrument shows the amount of current in the generator field and gives a means of adjusting the rheostat so that the two machines operate in parallel without undue cross currents, if rheostat adjustment becomes necessary after the machines are paralleled.

In order to use panels of small size, the voltmeter, common to all machines, and the synchronism indicator, can be placed on a swinging bracket.

Apparatus. The generator panel will be equipped with:

1 Ammeter
1 Field ammeter
1 Rheostat mechanism, for generator and
  exciter rheostats
1 Potential receptacle
1 Synchronizing receptacle
1 Field switch
1 Main switch

Proper plugs should be furnished with the instruments on the bracket, so that they can be connected, through the receptacles on the panels, to any machine. The main switch is usually not fused, overload and short circuit protection being provided on the feeder switches. Alternating-current machines are able to stand heavy overloads and short circuits much better than direct-current machines, so that damage is not so likely to occur, even should there be trouble between the machines and the feeder switches. This possibility is also remote if the wires are properly installed. The omission of fuses or other overload protection prevents trouble due to heavy cross currents when synchronizing and also prevents trouble on one feeder shutting down the whole station.

Feeder Equipment. Feeder circuits in such stations are usually equipped with fused lever switches. If the character of the load is such that fuses may be blown quite often, it will be cheaper in the long run to substitute circuit breakers for the fused switches. If these breakers are arranged to trip free from the operating handle, no switch is necessary in series, since the breaker can not be held in on trouble.

Equipment Providing Voltage Regulation. In case it is desired to install a voltage regulator automatically to keep the voltage constant, it will be necessary to operate the exciters in parallel as well as the generators. The simplest way this can be done is to add exciter switches on each of the generator panels. While this may crowd the panels somewhat, it saves the addition of a separate panel and may be satisfactory for small industrial plants. It will also be necessary to add a direct-current voltmeter and plug to the swinging bracket, and the necessary receptacles to the panels. The voltage regulator can be mounted on a separate panel together with the handwheels for the necessary equalizing rheostats.

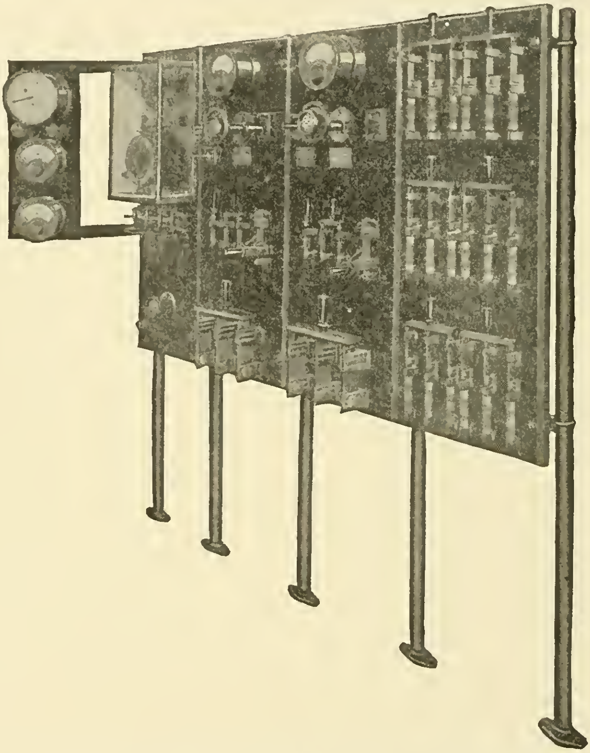


Fig. 32. Small Industrial Switchboard Provided with Voltage Regulation
Courtesy of General Electric Company

Fig. 32 shows a small industrial switchboard of the type described, consisting of:

- 1 Swinging bracket, containing—
  - 1 Synchronizing indicator
  - 1 Alternating-current voltmeter
  - 1 Direct-current voltmeter
- 1 Regulator panel
- 2 Combination generator and exciter panels
- 1 6-circuit feeder panel

Such an equipment is inexpensive, simple, occupies small space, and gives ample protection to machines and circuits. It does not give means of operating most efficiently in parallel. It does not have sufficient instrument equipment to allow complete station records which would show just what the station was doing. It does not include meters which would record the output in kilowatt-hours, and thus give an idea of the dollars-and-cents efficiency of the plant.

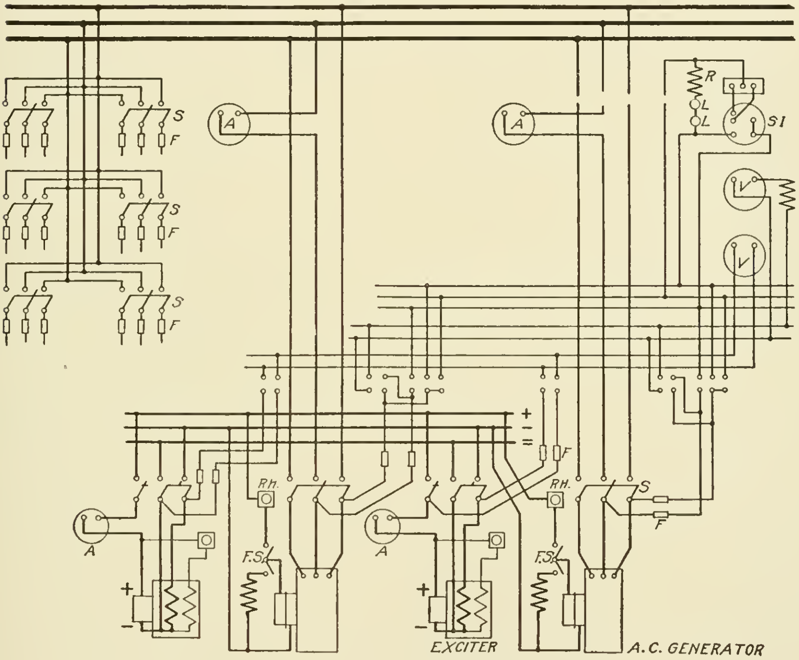


Fig. 33. Wiring Diagram for Switchboard Shown in Fig. 32

Fig. 33 shows the wiring diagram for the switchboard shown in Fig. 32, except that the regulator connections are omitted for the sake of simplicity.

LARGE INDUSTRIAL POWER BOARDS

In plants containing several generators of medium or large capacity, the total cost is so great that a small amount spent for what might be considered extras in a smaller plant is not noticed. The additions necessary to make the switchboard, not elaborate, but good, will cost so little, that any medium-sized plant can stand the expenditure. We find many industrial plants using thousands of kilowatts in generating capacity, and in such plants the best switchboard obtainable is none too good.

Requirements. Practice varies somewhat as to details among different engineers and among different manufacturers, but in general, the equipment used in the larger industrial plants will follow pretty closely certain fixed lines.

Panels. Slate panels seven feet six inches high are generally used instead of the smaller panels without sub-bases.

Voltage. The voltages used in the larger plants are 480 and 600 volts. Higher voltages are sometimes used where very large amounts of power are required and where the power must be distributed over a considerable area, but such plants are really individual problems, so that general rules can hardly be laid down for them.

Oil Switches. For the voltages which we are considering, most engineers recommend the use of oil switches throughout for machine circuits and for feeder circuits. Their use undoubtedly helps to make the plant safer, by removing some live parts from the front of the panels. They also have the ability to rupture large amounts of power without danger to themselves or their surroundings, and greatly reduce fire risk. They lend themselves to remote control, which becomes necessary in large plants, and in every way fit into the large industrial plant better than lever switches or air-break circuit breakers.

Generator Equipment. The equipment usually considered as minimum for generators in large plants is:

1 Ammeter
1 Voltmeter
1 Polyphase wattmeter
1 Rheostat mechanism
1 Double-pole field switch
1 Synchronizing receptacle
1 Governor control switch (when machine has motor-operated governor)
1 Nonautomatic oil switch
1 Watt-hour meter
Necessary instrument transformers

The loads are nearly enough balanced so that an ammeter only in one leg gives the current close enough for practical purposes. In plants where the unbalancing may become severe, a switch can be included to transfer the ammeter to the three leads of the secondaries of current transformers, so as to read all three legs, and a potential receptacle can be added to connect the voltmeter to all three phases.

Wattmeter. The wattmeter allows the loads to be properly adjusted, and together with the ammeter allows the rheostat to be adjusted for minimum wattless current, if it is found necessary to make voltage adjustments. The addition of a field ammeter is desirable, but not absolutely necessary.

Watt-Hour Meter. The watt-hour meter is omitted by some engineers, and each feeder is metered instead. This may be desirable, in order to make the proper charges against departments or sections of a factory. Best practice, however, requires watt-hour meters in one place or another, in order to run the plant scientifically and keep proper records of output to be checked against the cost of coal.

Double-Pole Field Switch. It will be noticed that the generator equipment includes a double-pole field switch. A double-pole switch is always used in order to entirely disconnect the generator field from the exciter bus. The machine is thus entirely disconnected from all sources of current when the main switch and field switch are open. One may then do any kind of work necessary about the machine without danger of a shock even from the field circuits. The voltage used for exciters is almost always 125 volts.

Exciter Equipment. The equipment for exciter circuits is a little different from that used on the ordinary direct-current machine, in that overload and short circuit protection is generally omitted altogether. The usual wiring diagram may be studied by noting the exciter panel in Fig. 33. The exciter is the most important piece of auxiliary apparatus in the station, and maintenance of the exciter circuits is absolutely necessary. There is really little chance of trouble between the exciters and the fields of the generators, and since the importance of maintaining service between them is so great, it is considered better to risk the burning out of an exciter at rare intervals than to risk the synchronous machinery by placing overload protection in the exciter circuits. When large exciters are operated in parallel driven from prime movers, there is some danger that a machine may under some conditions operate as a motor. Since this condition means reversal of the current in the main leads, a reverse current circuit breaker will give the necessary protection. With the above facts in mind, it will be seen that the switchboard equipment for an exciter is:

1 Ammeter
1 Voltmeter (common to all exciters)
1 Rheostat mechanism
1 Potential receptacle and plug
1 Triple-pole lever switch

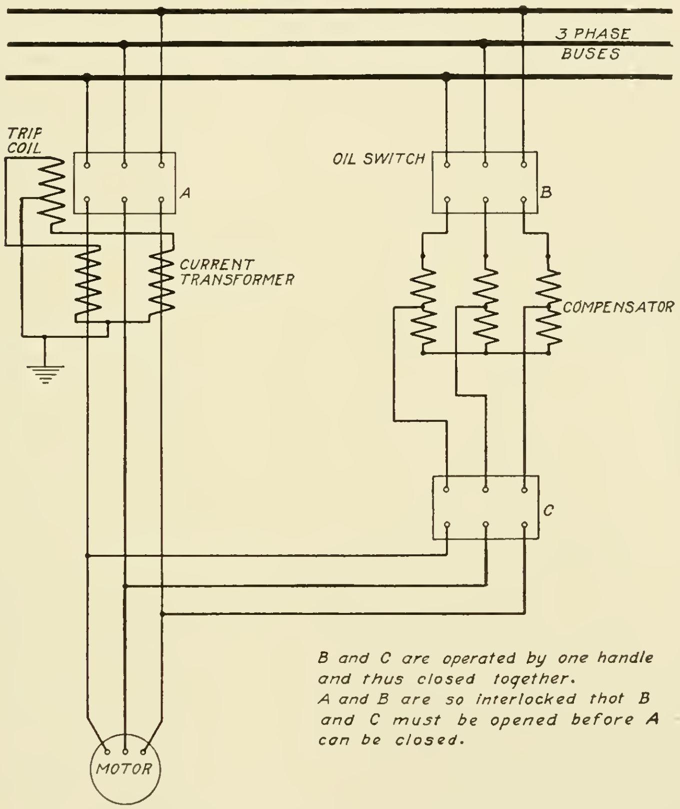
To this may be added, at times, the single-pole reverse current circuit breaker. Since stations are nearly always equipped with at least two exciters, a double-circuit panel is very commonly used. This would include double the equipment listed above, except as to the voltmeter and the plug.

Synchronous Motor Equipment. Exciters are often driven by synchronous or induction motors, and there are other machines which may be driven in the same manner. We must, therefore, consider the proper equipment for these motor circuits.

Synchronous motors require:

1 Ammeter
1 Field ammeter
1 Rheostat mechanism
1 Automatic oil switch
1 Field switch
Necessary instrument transformers

Compensator or Auto-Transformer. The motor may be started by means of a compensator or auto-transformer, and if this is done with the field open, a considerable voltage will be induced across the field winding. The field switch should, therefore, have barriers which will prevent accidental contact, or else be placed back of the panel with only an insulated handle brought to the front of the panel.



B and C are operated by one handle and thus closed together.
A and B are so interlocked thot B and C must be opened before A can be closed.

Fig. 34. Starting Arrangement for Synchronous or Induction Motors

If the current is so high that the starting switches can not be included with the compensator, then they must be mounted on the panel. Compensator or auto-transformer starting requires a switching arrangement having the equivalent of six poles on the starting side and three on the running side, for a three-phase motor.

This can be arranged with two three-pole oil switches on one side and one three-pole switch on the other side. Fig. 34 shows the wiring of such an arrangement. Since synchronous motors are sometimes used for power factor correction, an additional instrument is sometimes required for these panels. This may be a power factor indicator or a wattless component indicator. The latter is to be preferred, since it gives directly the kilovolt-amperes being supplied by the machine, for corrective purposes.

Induction Motor Equipment. Induction motors usually require only:

1 Ammeter
1 Automatic oil switch
Necessary instrument transformers

The extra switches for starting may be added in some cases where they can not be included with the compensator.

Feeder Circuits. Feeder circuits in industrial plants may be divided into power and lighting circuits, the wiring diagram for a three-phase feeder circuit for both power and light being shown in Fig. 35.

Where a circuit is used for power only, the equipment will consist of:

1 Polyphase indicating wattmeter
or
1 Ammeter
1 Automatic oil switch
1 Time limit relay (optional)
1 Watt-hour meter (optional)
Necessary instrument transformers

The indicating wattmeter gives a much more valuable reading than the ammeter, but the ammeter costs less and may give all that is required. The time limit on power circuits is a very valuable feature in most cases. It allows the tripping point to be comparatively low without causing the switches to be continually tripping out on momentary overloads, and yet insures that, should overload long continue, the circuit would be opened and saved from damage.

As to the watt-hour meters, no hard and fast rule can be given. Meters on the generators may save money, but meters on the feeders give just the data on which to charge departments and sections for the power they use. The circumstances in each case will have to determine where meters are to be used.

Separate Lighting Circuits. Usually separate lighting circuits are run out from the switchboard for supplying the whole plant or shop, and, as a rule, leave the switchboard as three-phase circuits, Fig. 35. Since the load is all single-phase, there is bound to be some unbalancing, which it is desirable to know.

The equipment will then consist of:

3 Ammeters or 1 ammeter with 3-way switch
1 Automatic oil switch
1 Watt-hour meter (optional)
Necessary instrument transformers

If the load varies rapidly from moment to moment for any reason, the three ammeters are essential. If, as is usually the case, the changes are very slow, one ammeter and a switch for reading all three phases are just as good.

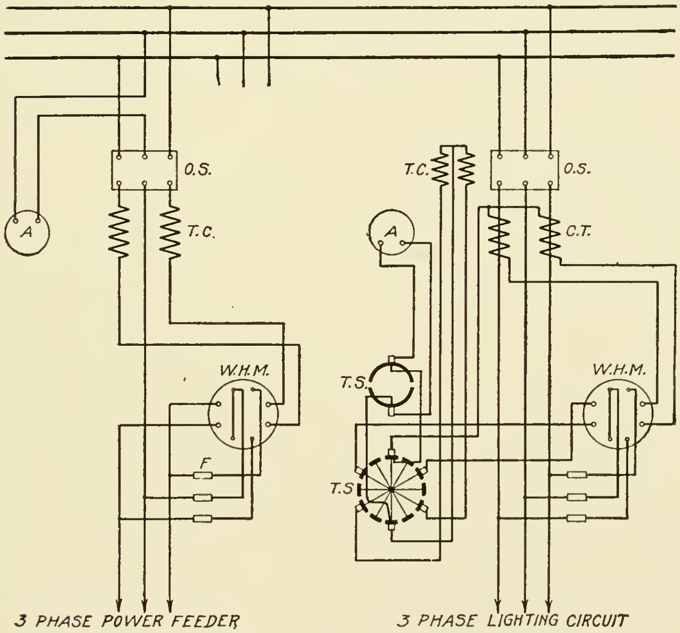


Fig. 35. Wiring Diagram for Three-Phase Feeder Circuit

The watt-hour meter is needed only if it is desired to know how much energy is being used for lighting service, or to complete the meter equipment, and gives a means of reading the total output of the station for any period.

Arrangement of Apparatus on Front of Panels. The arrangement of the apparatus on the panels is practically standard for all manufacturers. Instruments are always placed at the top of the panels, the rheostat handwheel on generator panels about the center, with the field switch at the right, and receptacle at the left. The oil switch operating lever is placed next, and the watt-hour meter on the sub-base. This arrangement places the various devices where they are most convenient. The instruments are easily observed when at the level with, or slightly above, the eyes. The field rheostat and field switch, which are closely related, are close together and easily operated. The oil switch lever is in a position where it can be easily and quickly operated. Readings of the watt-hour meter are made at longer intervals, so that its location at the bottom of the panel is not objectionable.

Arrangement of Backs of Panels. *Oil Switches.* The arrangement of the backs of the panels depends, for the voltages being considered, upon the amount of current to be handled. For small or medium currents, the oil switches are comparatively small, and can most conveniently be mounted directly back of the panels. The connections between switches and buses themselves are not so large or cumbersome as to make the back of the board crowded. When we consider, however, that a three-phase generator of 2000-kilovolt ampere capacity at 600 volts has a current of 2000 amperes, it will be seen that the connections occupy quite an appreciable space back of the panels. Oil switches for currents above 800 or 1000 amperes are very large and heavy. They not only occupy a lot of room that should be clear, but they prevent proper inspection of small wiring, and are not themselves as easily cared for as if they were some distance away from the panels.

Remote Control. In cases where large units are installed, or where for other reasons large switches, heavy connections, and buses must be used, best practice directs that the switch be remote from the panels. This allows the switches, buses, and connections to be arranged in a convenient and accessible manner, leaves the backs of the panels clean and easy to inspect or repair, and makes a better equipment in every way, both electrically and mechanically.

With mechanically-operated switches, the switch structure can be placed in any convenient location above, below, or back, of the switchboard, the only limitation being in the distance between panels and switches. With electrically-operated switches, the limitation as to distance is not so great, and they can be placed in almost any location. With remote control, it is, of course, necessary to use secondary instruments, trip coils, etc., throughout; only the secondary transformer leads and the necessary control leads, if electrically-operated switches are used, need be brought to the panels. Fig. 36 shows a section through a switchboard and switch structure, where the switches are mechanically operated. It will be seen that this arrangement will allow of a number of variations, and that the switches and buses might just as well be placed above or below the panels as back of them. Care should always be used to see that ample space is allowed for passageways. It is always better to have too much space than too little, and sufficient working room without danger to life is always an essential.

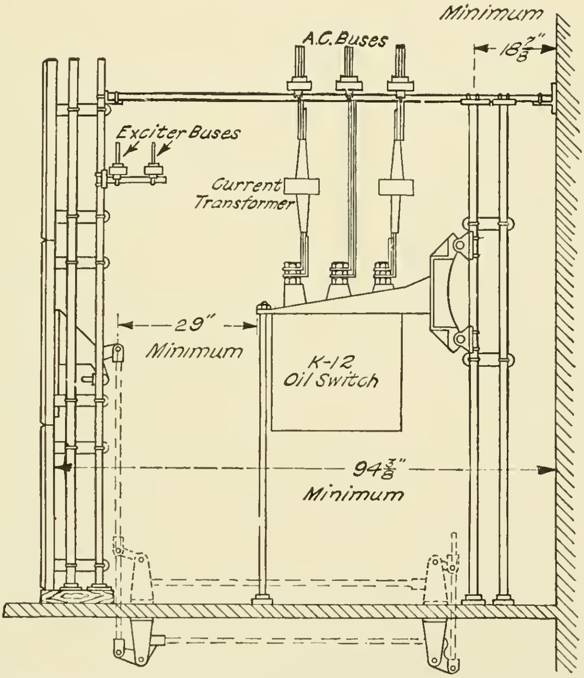


Fig. 36. Section Through Switchboard Showing Remote Control of Oil Switches
Courtesy of General Electric Company

Wiring. The backs of the panels themselves should always receive proper attention, as well as the equipment. On panels having several instruments, receptacles, etc., there may be considerable small wiring. The arrangement of these wires should be such that there are as few crosses as possible, they should be run as far as possible in straight horizontal and vertical lines, and should be cleated to the panels so that there will be no chance to get out of line. No wire smaller than consistent with proper rigidity should be used, regardless of the current to be carried. Numbers 12 and 14 B & S gauge are the sizes generally used. These small wires should have rubber insulation with braid finish and should be painted with flameproof paint.

CENTRAL STATION LIGHTING AND POWER BOARDS

The use of electricity in homes, stores, and factories has become so common that we find the central station supplying this service in every corner of the country. The smaller towns are just as progressive as the larger ones in this respect, and thus we have stations ranging in capacity from a few kilowatts up to many thousands of kilowatts.

Voltage. The voltage used in this country is almost universally 2300 volts, although in some places where larger areas are to be covered, it has been found convenient to use 4000 volts Y-connected with the neutral point grounded. This arrangement gives the standard 2300 volts between the neutral and any outside wire, and at the same time, gives the advantage of the higher voltage for transmission. In the larger cities, still higher voltages have been used, since the conditions there are somewhat special. In the following descriptions, the service will be assumed to be three-phase 60 cycles, 2300 volts.

Equipment in Small Plants. In the smaller plants, the same condition is encountered as in small industrial plants. The whole investment is so small that every effort is made to keep down the cost of the switchboard. The wiring diagram shown in Fig. 35 gives a good idea of the usual practice for small central station installations.

In the smallest plants, where only one generator is installed and where but one set of lines leaves the station, the whole equipment can be handled with one panel equipped as follows:

1 Ammeter
1 3-way ammeter switch
1 Voltmeter
1 8-point potential receptacle with plug
1 Field rheostat operating mechanism
1 Field switch
1 Triple-pole automatic oil switch
Current and potential transformers

Since a large part of the load on such plants is single-phase lighting, there is likely to be considerable unbalancing; and it is, therefore, the usual practice to include the three-way ammeter switch and the eight-point potential receptacle in order to read the current and voltage on all three phases. In some cases, only the exciter is supplied with a rheostat. Where both the exciter and the generator have rheostats, the mechanism can be made "concentric", arranged to operate both of them.

Exciter. In these plants, the exciters are usually driven by the same prime mover as the generator, so that if one is shut down both are shut down. In this case, a single-pole field switch to open the field circuit is all that is necessary.

Oil Switch. The oil switch in such plants is always mounted back of the panel, and the trip coils are usually connected directly in series with the main leads.

Precautions. The instruments should always be operated from the secondaries of instrument transformers. While they can be insulated for this voltage, all engineers recognize that it is dangerous to bring the wires carrying such voltage to the front of the board. In the past, even exposed lever switches carrying 2300-volt current were sometimes seen on the fronts of panels. The present practice is to eliminate from the front of the board, all voltages which are dangerous to life and to make the panels such that the operator can handle any circuit intelligently and quickly without having to look out for shocks or having his mind diverted by his own danger.

Two Outgoing Circuits. The above description covers the usual single-machine station. It sometimes happens that two outgoing circuits are necessary, and in such cases, another automatic oil switch is often added to the panel and connected in parallel with the first one on the generator side. This requires that two switches be opened to disconnect the machine entirely from the lines. This is not objectionable in a plant with only one machine.

Equipment for Larger Plants. When somewhat larger plants are considered, more than one generator is usually found, and it then becomes necessary to operate the machines in parallel. The same considerations as to parallel operation apply in this case as discussed in connection with power switchboards.

Synchronizer. The synchronizer and alternating-current and direct-current voltmeters, with their necessary plugs, are usually mounted on a swinging bracket at the end of the board.

Generator Panels. Generator panels are equipped with:

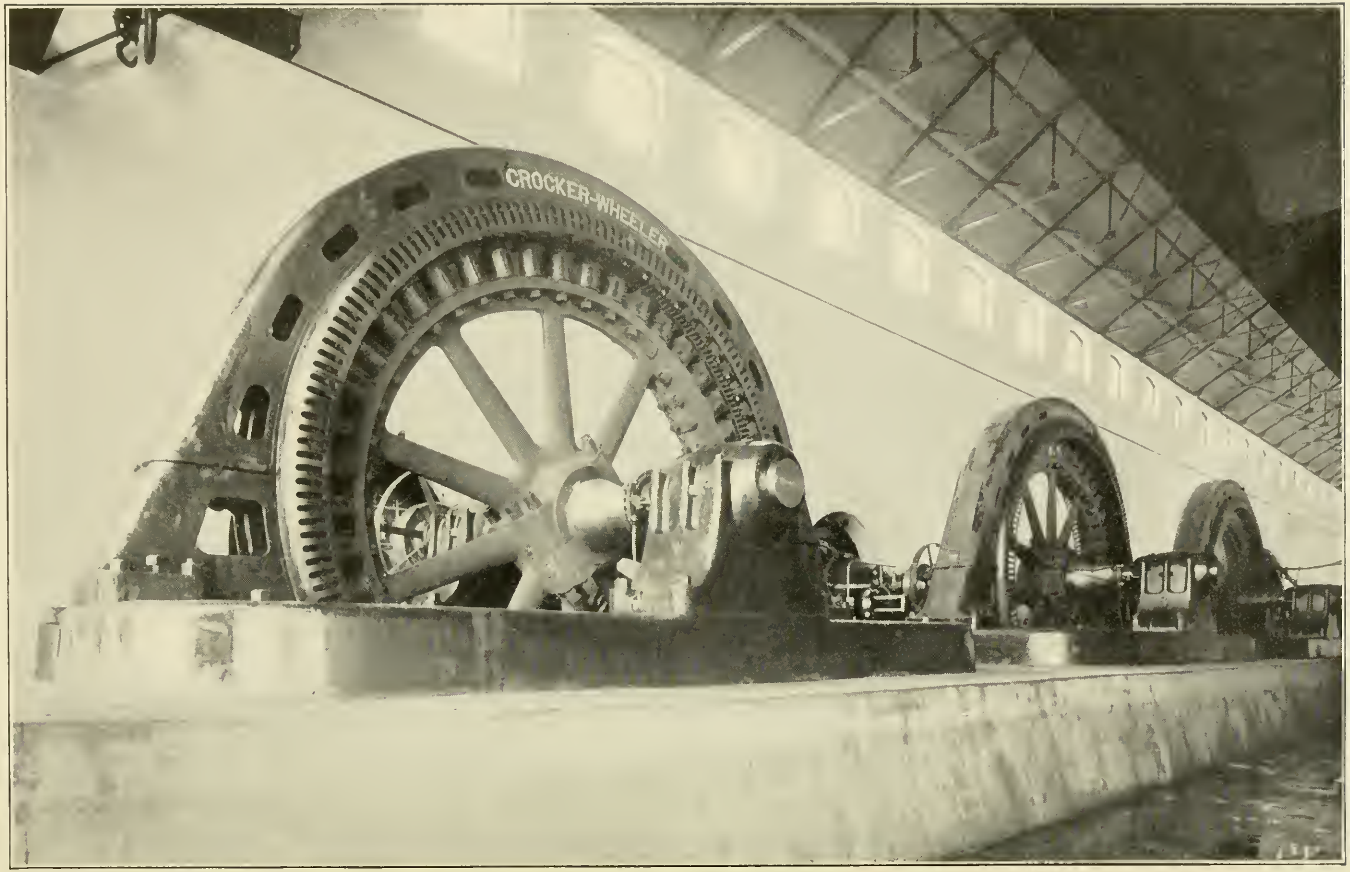
1 Ammeter
1 3-way ammeter switch
1 Field ammeter
1 Rheostat mechanism
1 Synchronizing receptacle
1 Potential receptacle
1 Field switch
1 Nonautomatic oil switch
Current transformers
Potential transformers

Voltage Regulator. With individual exciters for each machine and no voltage regulator, the above equipment is sufficient. However, when a voltage regulator is used, the exciters must be run in multiple, and the necessary exciter switches can usually be added to the generator panel. In this case, a potential receptacle is also added and the direct-current voltmeter is mounted on the bracket.

The wiring diagram for such an equipment will be similar to that shown in Fig. 33, except that oil switches are used instead of lever switches, and the instruments are operated from transformers instead of direct.

Separate Exciter Panel. In case one or two exciters are used to supply excitation for the whole station, it is necessary to install a separate controlling panel, with the following equipment:

1 Ammeter
1 Voltmeter
1 Rheostat mechanism
1 Potential receptacle
1 Triple-pole lever switch



THREE 6600-VOLT ALTERNATING-CURRENT GENERATORS INSTALLED FOR THE SANITARY DISTRICT OF CHICAGO AT LOCKPORT, ILLINOIS

Courtesy of Crocker-Wheeler Company

If a double-circuit panel is used, the above equipment will be double, except the voltmeter which will be common to both exciters.

Plants of this character do not usually contain rotary converters or synchronous and induction motors which must be controlled from the switchboard.

Feeder Circuits. Feeder circuits may be either single- or three-phase. Single-phase circuits will be equipped with:

1 Ammeter
1 Automatic oil switch (double-pole)
1 Current transformer

Double-circuit panels would have double the above equipment.

Three-phase panels will be equipped with:

1 Ammeter
1 Automatic oil switch (triple-pole)
1 Current transformer

Double-circuit panels will have double the above equipment. If the three-phase panels are to be used for power only, the above is satisfactory, but quite often some lighting may be taken from a three-phase line, and this may cause considerable unbalancing. A three-way ammeter switch and one more current transformer can be added, which will allow the current on all three phases to be read. The three-pole oil switches will, of course, always be equipped with two trip coils in order to give full three-phase protection.

Equipment for Small Central Station. Fig. 37 shows a small switchboard consisting of:

1 Swinging bracket
1 Voltage regulator panel
2 Generator panels
1 2-circuit feeder panel

This switchboard contains all the essential features for a small central station, gives a good appearance, and yet represents a small investment.

Equipment for Larger Central Stations. When we consider the larger stations, we can also consider better and more elaborate switchboards. As in industrial boards, the larger stations usually contain 90-inch panels. Better equipment is purchased, both because it is needed for the protection of the more expensive machines and because the proportion of switchboard to total investment will be smaller.

Generator Equipment. Generators are usually equipped with:

3 Ammeters
1 Voltmeter
1 Indicating wattmeter
1 Field ammeter
1 Rheostat mechanism
1 Field switch
1 Potential receptacle and plug
1 Synchronizing receptacle
1 Nonautomatic oil switch
1 Watt-hour meter
2 Current transformers
2 Potential transformers

The use of three ammeters gives the operator an instant check on the balancing of the current in the three phases, and is therefore better than using one ammeter with a three-way switch. The uses

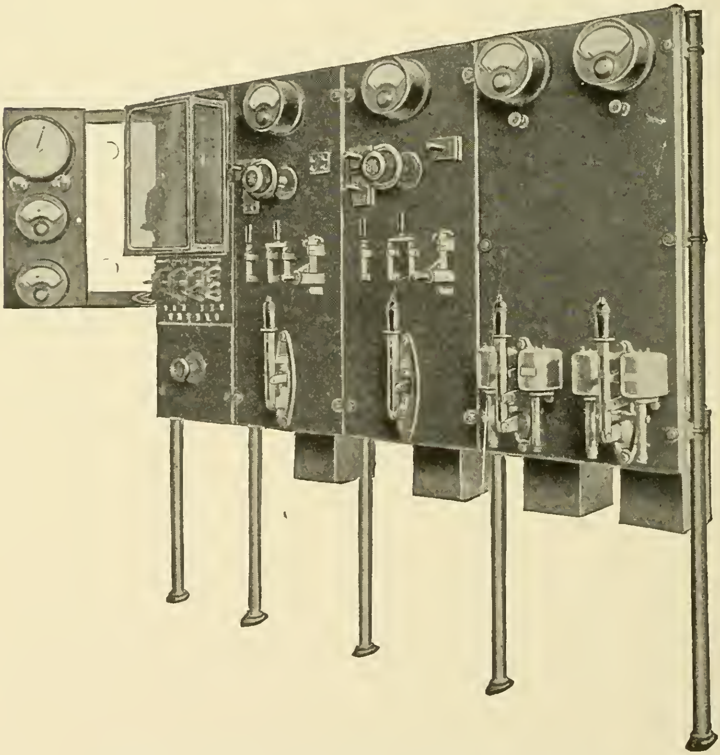


Fig. 37. Switchboard Equipment for Small Central Station
Courtesy of General Electric Company

of the field ammeter and indicating wattmeter have already been explained.

Current and Potential Transformers. It may be noted that, on the assumption of three-phase three-wire circuits, two current and two potential transformers have been included in every case. Where the circuits are 4000 volts with the neutral grounded or used for the single-phase feeders, three of the current and three of the potential transformers would be necessary.

Power can be measured or indicated by current and potential values from two phases on a three-wire circuit. On a four-wire circuit all three phases must be used. Wattmeters and watt-hour meters for four-wire circuits, therefore, have three current coils rather than two.

Exciter Equipment. The exciter equipment would be the same in a large plant as in a small one. Separate panels would always be used and reverse current circuit breakers might be used in some cases, as previously explained.

Where one or more of the exciters are motor-driven, the motor is usually of the induction type, and is equipped with an ammeter, an automatic oil switch, and necessary current transformers. If only one motor is used, this equipment is quite often mounted on the same panel with the voltage regulator.

Synchronous Motor Equipment. Where synchronous motors are used for auxiliary apparatus or other purposes, panels for them are usually equipped with:

1 Ammeter
1 Field ammeter
1 Wattless component indicator
1 Field switch
1 Rheostat mechanism
1 Automatic oil switch
Current transformers
Potential transformers

In case the motor is started from the switchboard, an arrangement of switches as described under "Industrial Boards" is used.

Rotary Converter Equipment. When rotary converters are used for obtaining two- or three-wire direct current for lighting service, panels must be furnished for the alternating-current side. The switching equipment is usually placed on the high side of the transformers supplying the rotary. The necessary equipment is:

1 Ammeter
1 Automatic oil switch
2 Current transformers

These machines are usually started from the alternating-current end and a starting panel is necessary. This panel is usually small and may be mounted close to the machine. When the rotary is three-phase, a double-pole double-throw switch is sufficient to connect it to half voltage starting taps on the transformers. The larger machines are usually six-phase and started from one-third and two-thirds voltage taps. This requires two triple-pole double-throw switches for starting.

Feeder Circuit Equipment. Feeder circuits for power only or for a mixed load of light and power will be three-phase. The equipment for them consists of:

1 Ammeter
1 3-way ammeter switch
1 Automatic oil switch
2 Current transformers
1 Watt-hour meter (optional)
2 Potential transformers (when watt-hour meter is used)

Three ammeters would be used in cases where the load varied rapidly, since the comparison of the three values could be seen at a glance.

Time Limit Relays. Time limit relays are often added to the equipment. Relays may be necessary at times to reduce the load on the current transformers by cutting out the oil switch trip coils except at the moment of operation under overload. The time limit feature is desirable for the same reasons as discussed under "Industrial Boards". There is another feature that makes the time limit desirable. The characteristics of a short circuit on an alternating-current circuit are that the current values rise almost instantaneously to a very high value and drop off again very quickly, gradually approaching a constant value. If the oil switches remain closed until after the first great rush of current, they will be much better able to open the circuit than if they should be called upon to do it just at the time when the current was greatest. All oil switch manufacturers give a very much greater rupturing capacity for oil switches equipped with time limit relays than for switches tripped instantaneously. There must, of course, always be a condition that the relays be set for such a value that the switch will open after the initial rush of current.

Single-Phase Feeder Circuits. Single-phase feeder circuits are usually equipped with:

1 Ammeter
1 Automatic oil switch
1 Current transformer

In cases where feeder regulators are installed, a compensated voltmeter is added to the above equipment. This instrument reads the voltage, not at the buses but at the end of the line or at the center of distribution, and it is always possible to tell how much

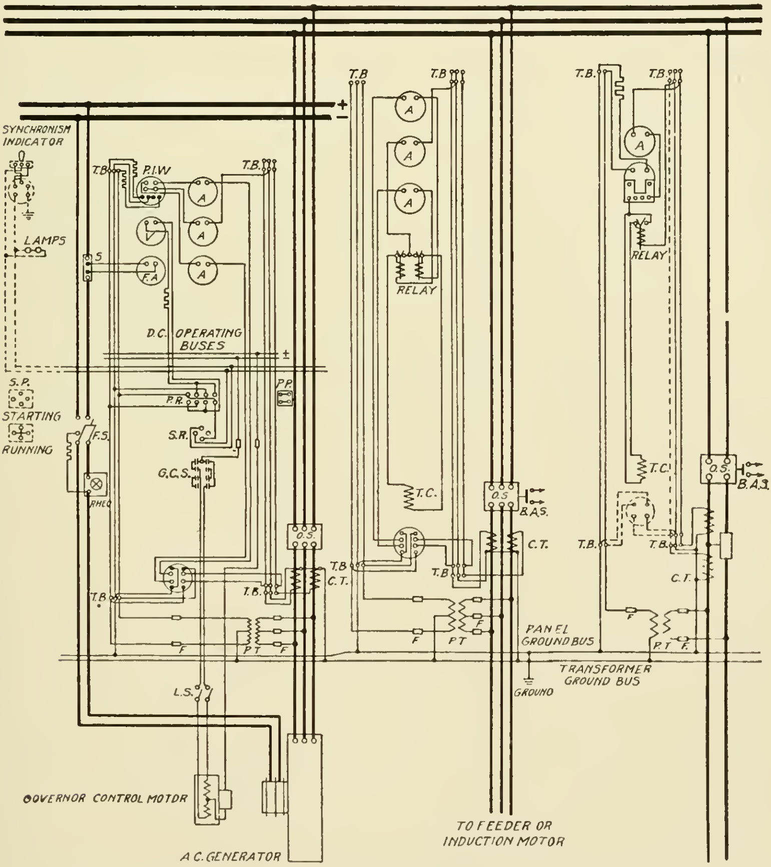


Fig. 38. Wiring Diagram for Switchboard Equipment of Standard Central Station

the voltage must be raised or lowered by means of the regulator. In case the regulators are automatic, the contact-making voltmeters furnished with the regulators are mounted on the feeder panels. These instruments do not properly belong to the switchboard equipment, but because of convenience in connections and because of their similarity to the switchboard voltmeters, are mounted on the panels.

Standard Central Station Equipment. *Wiring Diagram.* Fig. 38 shows the wiring diagram of a station containing equipment similar to those described in this section. It should be remembered that the equipments described are typical and that there are endless variations which may be made to meet special requirements or conditions.

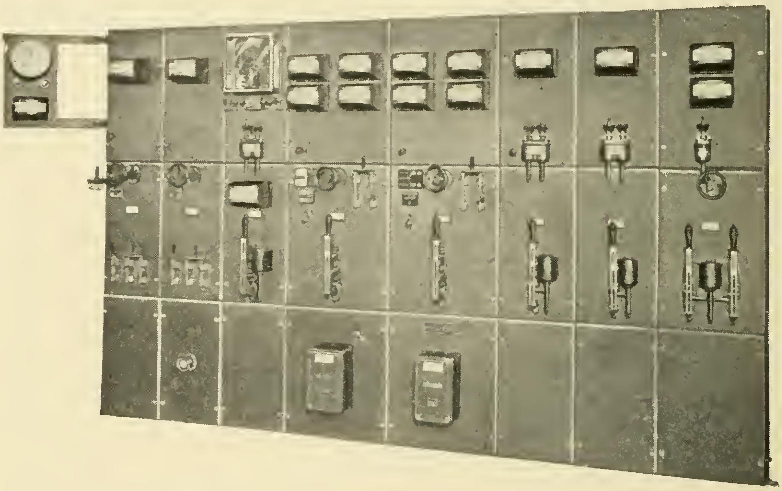


Fig. 39. Switchboard Equipment for Standard Central Station
Courtesy of General Electric Company

Switchboard. Fig. 39 shows the front view of a switchboard consisting of:

1 Swinging bracket, containing—
  1 Synchronizer
  1 Direct-current voltmeter
2 Exciter panels
1 Induction motor and voltage regulator panel
2 Generator panels
2 3-phase feeder panels
1 Single-phase feeder panel

Arrangement of Apparatus. The arrangement of the fronts of panels of the kind just described will be the same as that of panels for power service. The back of the board should be as free as possible from all high tension apparatus and wires. It is rather common practice to put the oil switches and buses directly back of the panels in small or medium size stations, but all engineers agree that it is much better practice to remove all voltages dangerous to life, from the panels. The slight added expense to make the switches operate under remote mechanical control is always worth the additional insurance against accident which it gives. Even when the switch and bus structure is placed directly back of the panels with a passageway

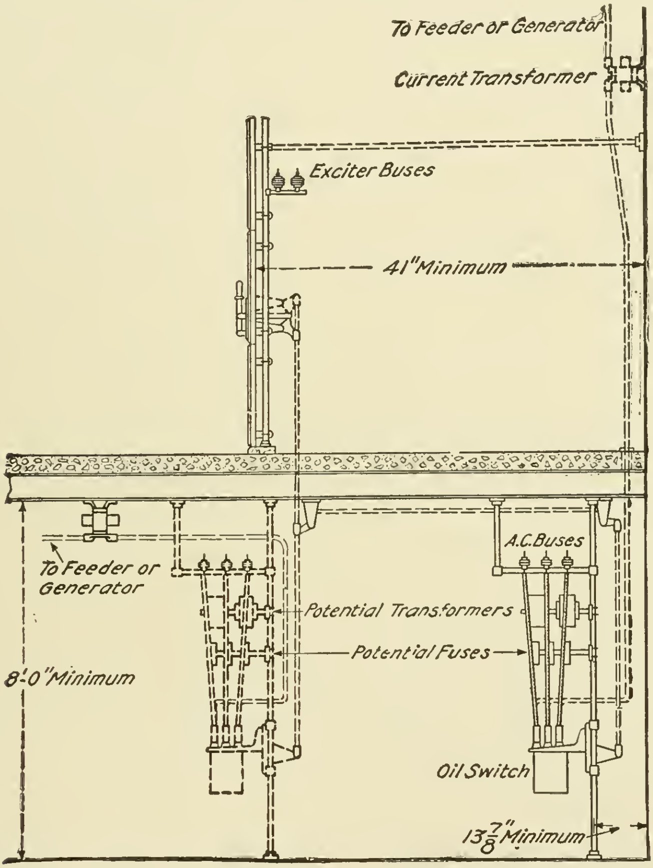


Fig. 40. Section of Switchboard and Accessories for Remote Mechanical Control Where Switches Are Mounted in the Basement

between there is less danger, and where this structure is entirely removed from the vicinity of the board, accidents are bound to be few. Fig. 40 shows two arrangements with remote mechanical control, where the switches, etc., are mounted in the basement below the switchboard.

Disconnecting Switches. Nothing has been said as yet in regard to isolating or disconnecting switches. When it is necessary to inspect or repair any of the high tension switching apparatus, either the station must be shut down for a time or else the work must be done with the apparatus live. Since the latter is very dangerous and the former hardly possible with a well-managed central station, it is usual to install disconnecting switches. These are plain lever switches properly insulated and so connected in the various circuits that opening them entirely disconnects the apparatus from the buses or live lines. Their use allows the operator to "kill" one circuit long enough to do the necessary work without shutting down the whole station or endangering the lives of the workmen. Disconnecting switches are always recommended in the better stations, even of small size. They can not be opened under load.

RAILWAY SWITCHBOARDS

Voltage. There is really no definite practice in regard to the alternating-current voltage in railway stations supplying direct-current railways. Since three-phase rotaries require 370 volts and six-phase rotaries require 430 volts, these voltages have sometimes been used where a large number of rotaries were installed in the generating station. The use of these voltages, of course, does away with step-down transformers, but it also makes the amounts of current to be handled very large in most cases and increases the cost of the switching equipment to a marked degree. Perhaps the voltage most often used is 2300 volts. In stations supplying single-phase or three-phase alternating-current railways, the generating voltage is usually the same as the trolley voltage, 6600, 11000, or whatever may be used.

Generator Equipment. Where the current generated is used for railway purposes only, it is not necessary to consider the question of balancing between phases, since all the apparatus operated is polyphase, and practically no unbalancing occurs. One of the generator equipments recommended in many cases is as follows:

1 Ammeter
1 Indicating wattmeter
1 Wattless component indicator
1 Watt-hour meter
1 Potential receptacle
1 Synchronizing receptacle
1 Rheostat handwheel
1 Field switch
1 Governor control switch
1 Nonautomatic oil switch
2 Current transformers
2 Potential transformers

A frequency indicator is usually mounted on the gauge board of the prime mover, and a voltmeter is mounted on a bracket at the end of the board along with the synchronizer.

From what has previously been said in regard to the operation of alternating-current generators, it will be seen that instruments are included in the above list to take care of every condition. Means are provided for proper adjustment of speed and field strength. Likewise means are provided for reading the true power and the wattless component, the line amperes, and the voltage. A watt-hour meter is included so that a record is obtainable of the exact number of kilowatt-hours delivered by the generator for any period. The equipment has no part that is useless and yet includes every desirable feature.

Exciter Panels. Exciter panels for these stations include the same equipment as for lighting stations. Exciter panels sometimes include switches for the control or operating buses wherever electrically-operated switches are used and are operated from the exciter bus.

Rotary Converter Equipment. Rotary converters, either in generating stations or sub-stations, require transformers to obtain the proper voltage for producing a given direct-current voltage, except where generators are wound for the voltage desired. The control equipment is placed on the high side of these transformers, starting switches only being on the low side.

The equipment usually includes:

1 Wattless component indicator
1 Automatic oil switch
1 Current transformer

When several rotaries are installed, a single wattless component indicator may be used, transfer switches being supplied for each machine.

Where the voltage is high, as in a sub-station, the rotary panel may be eliminated entirely from the main switchboard. The necessary transfer switches can be placed on the direct-current panel and the high tension oil switch operating lever placed close to the switch.

Synchronous Motor Equipment. Synchronous motor equipments include:

1 Ammeter
1 Field ammeter or 1 wattless component indicator
1 Automatic oil switch
1 Current transformer
1 Potential transformer (when needed)
1 Field switch
1 Rheostat mechanism

If placed in the generating station, the motors may be started from compensators, and switching arrangements should be properly provided for. In sub-stations, however, where transformers are necessary anyway, the motors are usually started from low voltage taps on the transformers the same as rotary converters.

Induction Motor Equipment. Induction motor equipments are the same as in lighting practice, except that in sub-stations they will be started from low voltage transformer taps instead of from compensators.

Oil Switch Requirements. In connection with rotary converters, induction and synchronous motors when used for driving direct-current railway generators, it must be remembered that the oil switch should always trip instantaneously. If time limit relays were used, the additional time required to trip the oil switch when a short circuit occurred on the direct-current end, might cause the direct-current commutator to flash over. Other circuits, such as feeders and lines to transformers, may be equipped with time limit relays.

Line Equipment. Lines leaving the generating station are usually at high voltage. The equipment is:

3 Ammeters (or 1 ammeter with 3-way switch)
1 Automatic oil switch
2 Current transformers

On the higher voltages, it is usually much cheaper to use series ammeters mounted on proper insulators and supported from the wall out of reach of the operator. The oil switch can then be tripped by series relays, and the expensive high voltage current transformers are eliminated. Only a small panel for the operating lever of the oil switch is necessary, and it should be mounted near the switch.

The incoming lines in sub-stations are usually equipped with an automatic oil switch only, which may have series trip coils for the higher voltages and be controlled the same as switches on outgoing lines. A voltmeter is sometimes installed on incoming lines, in which case a potential transformer is necessary. The voltmeter itself may be placed on a swinging bracket. In connection with the series trip, it should be remembered that these devices have marked disadvantages in some places. They are live when the lines are live. If adjustments will be necessary, either for current or time, with the lines live, such devices can not be considered.

All high voltage lines which may be live from outside the station should be equipped with electrostatic voltage detectors. These devices indicate when there is voltage on the system, and while they do not show the value, they act as a warning and give a means of knowing when the lines are live.

Single-Phase Equipment. Where generators and feeders are used for single-phase railways, the equipments are similar to the ones described. Slight changes are made to take care of the change from three- to one-phase, but the same general recommendations are followed. Fig. 41 shows the wiring diagram of a railway generator and a six-phase rotary converter, and gives an idea of the equipment generally used.

Arrangement of Switching Apparatus. The arrangement of the switching apparatus in a railway station follows in general the same lines as in lighting and power central stations. The fact that outgoing lines are usually at very high voltages modifies this to some extent. The high tension switches, current transformers, etc., are usually entirely separated from all apparatus of lower voltages. The high tension switching equipment then becomes entirely separated from the switchboard proper.

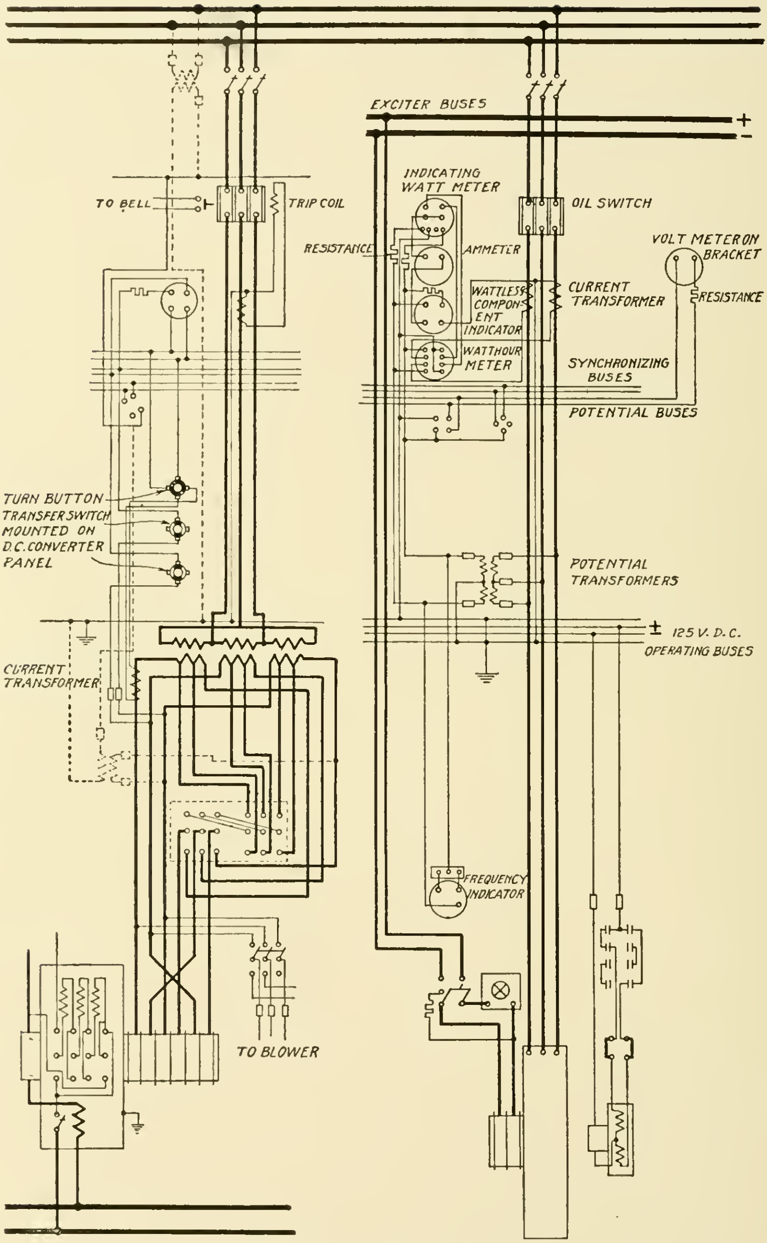


Fig. 41. Wiring Diagram for Railway Generator and Six-Phase Rotary Converter

TRANSMISSION SYSTEM SWITCHBOARDS

Voltage. In nearly all interurban railway systems, it is necessary to transmit power to sub-stations at more or less high voltage. In waterpower systems, high voltage lines are usually necessary in order to reach a market for the power developed. Now, the modern tendency is to operate central stations in groups tied together by means of high voltage lines. Thus, we have a very large number of problems involving the control and protection of lines ranging in voltage from 13,200 volts to 150,000 volts. Lines at 100,000 or 110,000 volts are becoming common all over this country, and at least one line is in course of construction which will transmit at 150,000 volts.

Transformer Requirements. These voltages are always obtained by means of static transformers, and these transformers must be properly protected. Trouble on the lines will rarely be communicated to the transformers if proper line and lightning protection is provided, but trouble may develop in the transformers themselves.

Reverse Energy Relays. Where several banks of transformers are operated in parallel, if one transformer breaks down and causes a short circuit within itself, the trouble will be fed from both low and high tension sides. In other words, the relative direction of flow of power will be reversed on one side or the other of the transformer in trouble, depending on whether the source of power is on the low or high tension side of the station. A relay which will operate when this condition occurs can be arranged to trip both the low and high tension oil switches, thus entirely disconnecting the transformer and relieving the system of trouble.

Inverse Time Limit Relays. Where more than two banks of transformers are operating, the same result can be obtained by installing inverse time limit relays on the side next the source of power and connecting them to trip both low and high tension switches. The action will be as follows: The sum of the currents being fed from the other transformers into the one in trouble will equal the current in the transformer in trouble. Since the time of tripping is inversely proportional to the current flowing, the relay on the transformer in trouble will operate more quickly than those on the other transformers, and the trouble will be disconnected from the system. Ammeters are sometimes installed on the transformer circuits to check the division of load between the various banks. They are considered desirable but not absolutely necessary.

Equipment for Outgoing Lines. Outgoing lines at high voltage require:

3 Ammeters
1 Automatic oil switch

The three ammeters give a check on the condition of the lines, show up grounds and broken lines, and are always desirable. They may be series instruments mounted on the wall on suitable insulators, and while accurate readings can not be obtained from them, they give what is desired and save the use of high voltage current transformers.

High Voltage Oil Switches. High voltage oil switches are very large and require plenty of space. They are usually installed at a considerable distance from the switchboard proper and are not operated from the panels unless they happen to be electrically operated. Engineers recommend that as little switching as possible be done on the high side of the transformers, so that the high voltage switches are seldom operated except in case of trouble. Small panels carrying the operating levers can be mounted close to the switches. The automatic feature of the oil switch can in some cases be obtained by means of series trip coils (or series relays if the switches are electrically operated), but the limitations of these devices should always be considered.

Equipment for Incoming Lines. Lines coming into the station from a single transmission line are often equipped with disconnecting switches only on the high tension side, all the switching being done on the low side. When several taps are made from the same line, or where duplicate lines feed a common bus, automatic oil switches are necessary on the high side of the transformers. These switches may be arranged in the same way as for outgoing lines.

It should be remembered that, for very high voltage, all switching equipment and instrument equipment become very expensive. The simplest equipment which will give the necessary protection is usually the best.

Arrangement of High Voltage Devices. All devices requiring current and potential transformers should, as far as possible, be placed on the low side of the transformers. It is needless to say that all high voltage devices and wiring are placed as much as possible where they can not be touched. Such equipment is best placed in separate rooms or buildings, and only those allowed about it who are familiar with the danger involved.

GENERAL SWITCHBOARD REQUIREMENTS

The preceding sections have covered, in a general way, the equipments used for all kinds of circuits for various classes of service. There are some general considerations which will apply to any switchboard and in any kind of a station.

Simplicity. We should always remember that complication of any kind not only increases the expense but increases the danger. It should also be remembered that it pays to get the best equipment possible, however simple it may be. Good equipment can be obtained from many of the larger manufacturers made up in standard lines to meet almost any condition. Since no drawings are required and no engineering is necessary on such standard lines, the prices are always lower than on panels made to meet special requirements.

Quality. It should not be overlooked that the workmanship and material used in assembling a switchboard have as much to do with its reliability as the apparatus mounted on it. Neatness and system in running wires and connections make a switchboard easy to inspect and repair, and add greatly to its appearance. All these things should be considered as well as the apparatus used, and only by a combination of good apparatus and good workmanship can one obtain a good switchboard.

LIGHTNING PROTECTION

There is practically no place which is free enough from lightning disturbances to permit of disregarding the question of protecting electric circuits against such disturbances. In many places, we find low voltage direct-current lines covering a considerable area and giving fair service, without lightning protection, but most engineers are not inclined to run such risks. The damages resulting from a severe electrical discharge may be so great that adequate protection is worth a large investment. Any line which leaves a building overhead should have lightning arresters.

DIRECT-CURRENT LINES

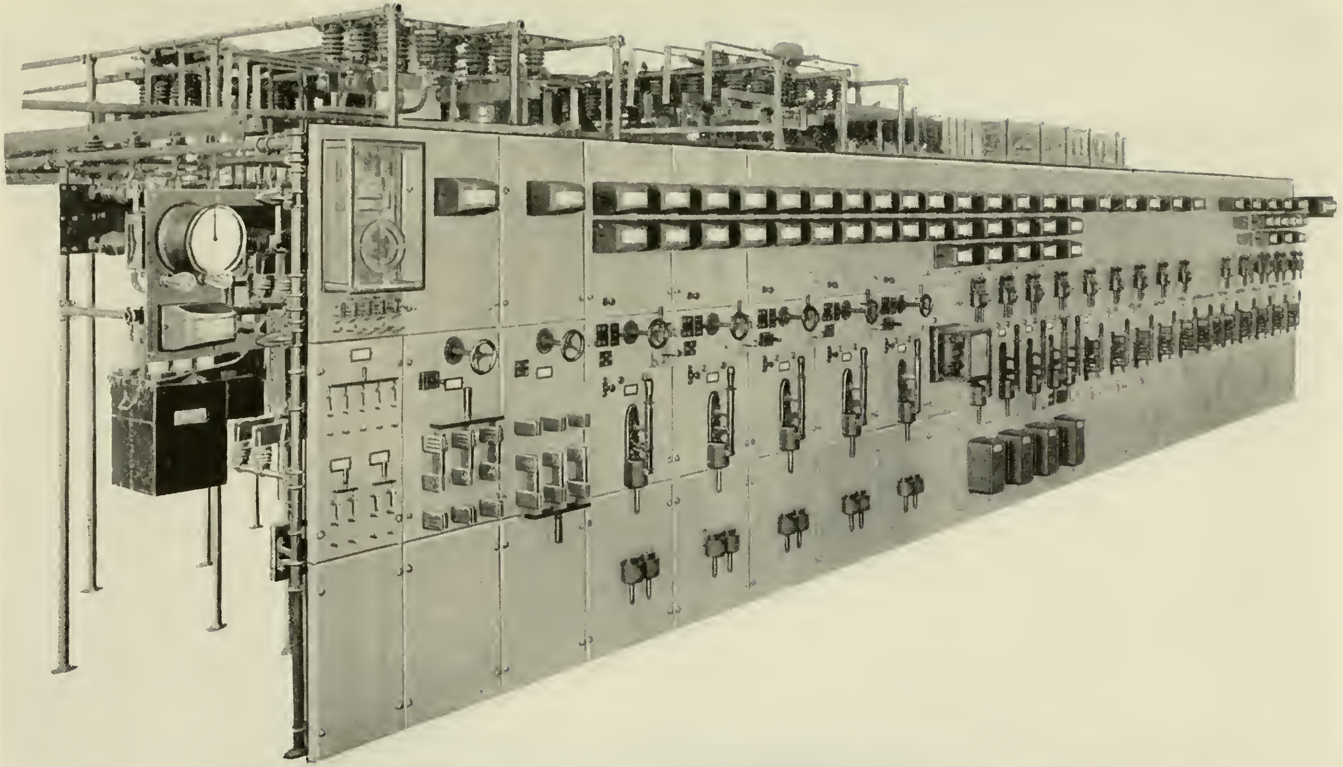
Lightning Arresters. *Overhead Lines.* On direct-current overhead lines, the practice has been to connect a lightning arrester to each ungrounded wire which leaves the building; the other side of the arrester, of course, being grounded. Choke coils have usually been made by coiling a section of the wire just before the lightning arrester is attached.

Underground Lines. Underground lines are not, of course, subject to the same troubles in this respect as the overhead lines. However, considerable trouble is sometimes experienced due to static discharges, and lightning arresters are often used to relieve this condition.

ALTERNATING-CURRENT LINES

Difficulties on Alternating-Current Lines. Alternating-current circuits have always given more trouble from lightning than direct-current circuits, and more effort has been devoted to working out the best protective apparatus for these circuits. When we think of the wide range in conditions that must be met in alternating-current circuits, it is plain that the problem is a big one. Any lightning protective apparatus not only must be able to dissipate a direct discharge, but it must be able to place itself immediately in condition to receive another discharge. It must prevent the high voltages often used from forcing dynamic current through the arrester, thus causing a short circuit on the system. It must be susceptible to voltage disturbances due to any cause whatever, even though they may not be from lightning.

Lightning Arresters. *Overhead Lines.* All overhead alternating-current lines leaving a station are always equipped with lightning arresters of some type. These arresters should be attached to the lines just as they leave the building and should be connected outside all other apparatus. Some means should always be provided for disconnecting the arrester from the line, for inspection, adjustment, or repairs, unless the voltage is low enough so that the lines can be worked live. Choke coils are always used to insure the discharge being carried off at the arrester and prevented from reaching the apparatus. Since the discharges are of very high frequency, the



6600- AND 3500-VOLT VERTICAL SWITCHBOARD OF THE KYOTO ELECTRIC COMPANY OF JAPAN

Courtesy of General Electric Company

choke coils will have considerable effect, although they would not affect the flow of current at the operating frequency.

Underground Lines. Where high voltage alternating-current lines are operated underground, lightning arresters are nearly always used to relieve them of static charges. The discharges from such lines may become very severe, especially if much switching is done, and the lightning arrester is a very important part of the equipment.

On Buses. Recently in many large stations it has been found that the switching operations cause so much voltage disturbance that lightning arresters have been installed in the station and connected to the bus. Of course, no choke coils are used, since the discharge may come from either side of the bus.

SWITCHBOARD DEVICES

WATT-HOUR METERS

DIRECT-CURRENT WORK

The measuring of the power generated by a machine or the power delivered to a circuit, is of the utmost importance, and the meters used for this purpose must be accurate, steady, and reliable.

Thomson Type. In direct-current work, the Thomson meter has for years been used more than any other. It consists of a motor having its armature connected across the line and its field in series with the line. The load is furnished by placing a metal disk on the motor shaft which rotates between permanent magnets. The shaft is connected to a train of gears which operate pointers which in turn move over small dials. The speed of the motor increases in proportion to the power flowing in the circuit. The movement of the pointers over the dials within any time gives the total watt-hours. The magnets on these meters are usually astatically placed to prevent the effect of stray fields.

Mercury Type. Another type of meter, which is radically different from the Thomson meter, is the mercury meter. In this meter, a copper disk is placed in a cup of mercury. The main current or a shunted portion of it is brought to the mercury cup and flows across the disk diametrically. A field is provided consisting of an iron core with a fine wire winding connected across the line. The currents flowing in the field and in the disk cause the disk to rotate. The shaft is attached to the usual train of gears. The chief advantage of this meter is that it can be operated from a shunt, and it is therefore unnecessary to place the meter where it will be affected by stray fields. This is also an advantage at times in arranging the front of a switchboard, since the meter can be placed wherever it is most convenient without regard to the main connections back of the panels.

ALTERNATING=CURRENT WORK

Induction Type. For alternating-current work, there is no question but that the meters built on the induction principle have proved their right to first place. They usually consist of a disk of aluminum on a vertical shaft, rotating in the field set up by two sets of coils. The coils are connected, one across the line, and one in series with the line. They are so wound that the current in the potential coil is out of phase with the current in the current coil, by 90 degrees. The turning torque is proportional to the product of the instantaneous values of current in the two coils or the power in the circuit. Load is furnished, as in other cases, by an aluminum disk rotating between permanent magnets. These meters when well made have all the good points desirable in a watt-hour meter, including reasonable cost.

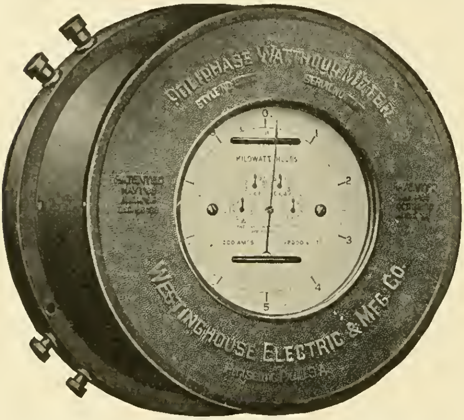


Fig. 42. Westinghouse Polyphase Watt-Hour Meter
Courtesy of Westinghouse Electric and Manufacturing Company

Mercury Type. Alternating-current meters are also built on the mercury principle. They are quite similar to the ones for direct-current work. With the alternating-current meters, the line current is usually passed through the field. The line voltage is stepped down to a low value by means of a small internal potential transformer to obtain current for the armature.

Commercial Types. Watt-hour meters for switchboard service are usually better finished than those used for other purposes.

They are often mounted in glass cases, and when in metal cases, are finished to harmonize with the other equipment of the switchboard. Figs. 42 and 43 show examples of watt-hour meters of different manufacture. Fig. 42 is a polyphase induction watt-hour meter manufactured by the Westinghouse Company, while Fig. 43 is a Sangamo mercury meter for direct current.

INDICATING INSTRUMENTS

DIRECT-CURRENT WORK

D'Arsonval Type. In direct-current work, the only instruments used are ammeters and voltmeters. Practically all manufacturers are now building instruments on the D'Arsonval principle. When properly made, the D'Arsonval is considered the best instrument for all ordinary work. This instrument consists of permanent magnets between the poles of which is suspended a coil with an iron core which is free to turn. The coil is held normally with its plane parallel to the lines of the field of the permanent magnets. When current passes through the coil, it tends to turn so that it stands at right angles to the lines of the field. This tendency is opposed by springs. Damping is furnished by winding the coil on an aluminum

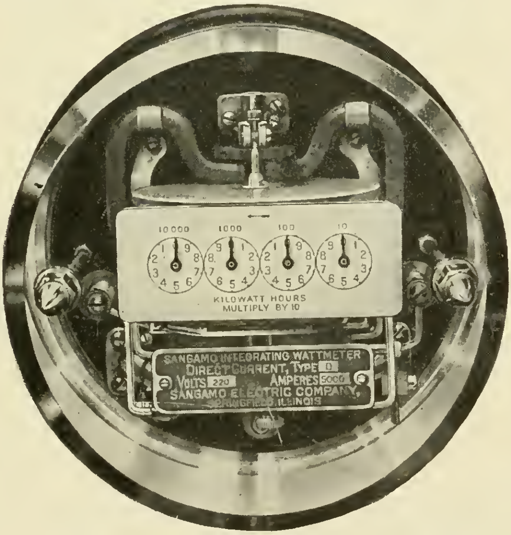


Fig. 43. Direct-Current Integrating Wattmeter
Courtesy of Sangamo Electric Company

loop. The movement of this loop in the magnetic field causes eddy currents to be set up and this makes the coil come to rest quickly.

The scales of these instruments are naturally uniform. Having permanent magnets, they show polarity by reversing with change in polarity. They require heavy shielding to prevent errors due to stray fields.

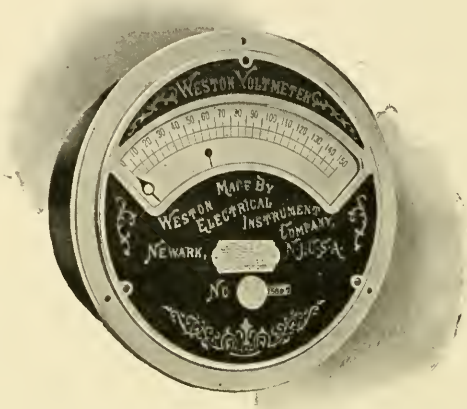


Fig. 44. Flush Type Direct-Current Voltmeter
Courtesy of Weston Electrical Instrument Company

Thomson Astatic Type. The Thomson astatic instruments are built on somewhat the same principles as the D'Arsonval instruments, with the following changes: The permanent magnets are replaced by four electromagnets astatically arranged. Magnetic control is used instead of spring control. These instruments being astatically arranged are not affected by stray fields even of very great magnitude. The strength of the field and the strength of the controlling force both vary with the excitation, so that a wide range in exciting voltage is possible.

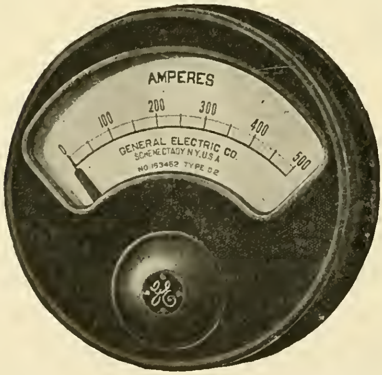


Fig. 45. Direct-Current Switchboard Ammeter
Courtesy of General Electric Company

They are naturally more expensive than the straight D'Arsonval instrument, but have a very marked advantage in some situations.

These instruments, when built as ammeters, operate from shunts. The voltmeters are the same as ammeters, but are connected through a resistance across the line.

Recording Type. Both ammeters and voltmeters are obtainable in the curve-drawing types. In these instruments the scale is replaced by a chart moved at a fixed rate by clockwork. The pointer is fitted with a pen which travels over the chart. The combination of the motion of the pointer and the motion of the chart causes the pen to draw a curve which shows the variations of current or voltage, as the case may be. Both time and current or voltage values are marked on the chart, so that it furnishes a permanent record.

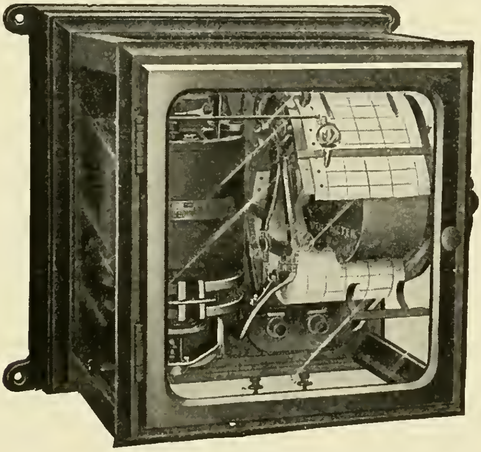


Fig. 46. Direct-Current Curve-Drawing Ammeter
Courtesy of General Electric Company

Curve-drawing ammeters are built both of the D'Arsonval shunted type and of the plunger type. Figs. 44, 45, and 46 show examples of direct-current instruments.

ALTERNATING-CURRENT WORK

In alternating-current work there are more kinds of instruments, and two or three different principles of operation are used.

Inclined Coil Type. For ammeters and voltmeters one of the most familiar types is the inclined coil instrument. In this instrument there is a vane of soft iron moving inside a fixed coil. The field set up by the current in the coil is at an angle with the vane. The vane then tends to place itself parallel to the field. Spiral springs are arranged to oppose the motion of the vane, and a pointer is attached and moves over a graduated scale.

Magnetic Type. Another similar type has a curved piece of iron inside the fixed coil. A second piece curved in the same way is mounted on the shaft and is free to turn against the pressure of the spring. When current flows in the coil, the two pieces of iron are magnetized alike and repel each other, causing the pointer to move over the scale.

These instruments show some slight errors due to changes in wave-form and frequency, but are accurate enough for all commercial work. They are simple and durable and have very good qualities for switchboard service.

Dynamometer Type. In instruments of the dynamometer type, there are a stationary coil and a movable coil. These coils normally stand at an angle, but when current flows in both coils they tend to place themselves parallel, so that the fields set up by both are in the same direction. The resultant strength of the two fields determines the torque. Torsion springs oppose the force of the coils. The usual pointer and scale are provided.

These instruments, when properly made, are usually considered the most accurate for alternating current. They are free from errors due to changes in wave-form or frequency, and when well shielded are free from the influence of external fields.

This principle of operation is used for ammeters, voltmeters, wattmeters, power factor indicators, and synchronizers.

Induction Type. Several manufacturers are building instruments which operate on the induction principle. These instruments are similar to the induction watt-hour meters. A metal disk is placed within the influence of two fields set up by alternating current flowing in coils. Current is induced in the disk, and the reaction between this and the fields causes the disk to rotate. The torque is proportional to the resultant fields and is opposed in most cases by springs. The position of the pointer then is the resultant of the forces of spring and fields.

Any of the instruments built on other principles can also be built on this principle. The chief advantage of these instruments is that they have very long open scales. They are usually made round pattern and then have scales covering about 300 degrees of the circle. They can not be used on circuits which vary greatly in frequency. These errors are small enough to make the instruments commercially satisfactory in the average plant, since the variation in frequency is small.

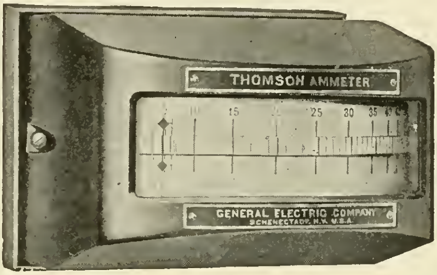


Fig. 47. Thomson Inclined Coil Ammeter
Courtesy of General Electric Company

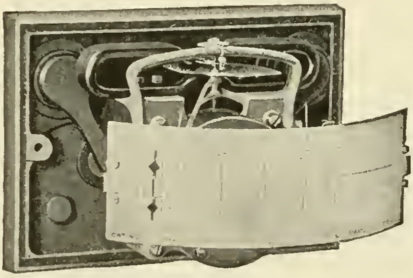


Fig. 48. Thomson Ammeter with Cover Removed

Hot Wire Type. Another principle used for the operation of alternating-current instruments is the hot wire principle. In such instruments, a current is passed through a wire which is fixed at one end and arranged to rotate a pointer at the other. The temperature of the wire, and hence its expansion or contraction, varies with the current flowing. The instruments can therefore be calibrated to read current or voltage. Quite a number of schemes have been employed for obtaining motion of the needle from the motion of the wire, but the principle of operation is always the same. These instruments have no iron and are free from errors due to changes in frequency or wave form. They are also free from the influence of external fields. They can be calibrated on direct current as well as on alternating current, which may be an advantage at times.

The ammeters have a small range in capacity without a shunt, and are little used for general commercial work. They are also sluggish, and are therefore not good for use on rapidly fluctuating loads. They are particularly well suited to high frequencies and are used for wireless telegraph work.

Commercial Types. A number of types of ammeters and voltmeters are obtainable from several manufacturers, which are built on the inclined coil or iron vane principles.

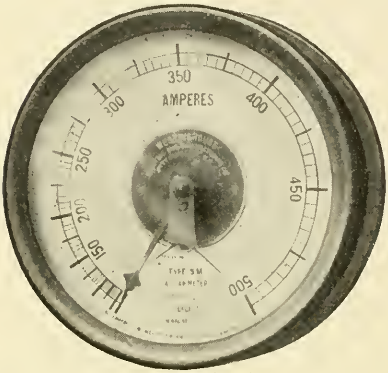


Fig. 49. Induction Ammeter
Courtesy of Westinghouse Electric and Manufacturing Company

Fig. 47 shows a Thomson inclined coil instrument in a horizontal edgewise case, and in Fig. 48 is shown the instrument without the case. These instruments have magnetic damping, laminated iron shields, and an iron case. They represent the best product of the General Electric Company.

The best-known induction ammeters and voltmeters are built by the Westinghouse Electric and Manufacturing Company. Fig. 49 shows one of their latest instruments mounted in a seven-inch round case, Fig. 50 showing the same instrument disassembled. It will be noted that the scale is very long and quite open except at the beginning.

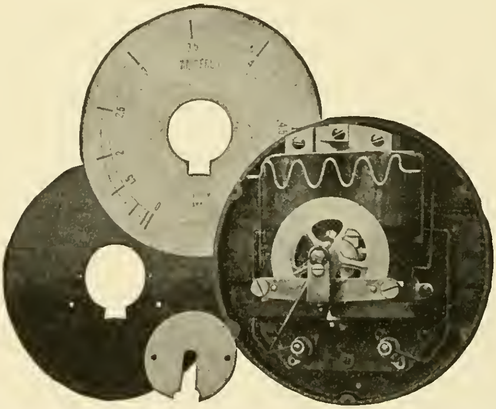


Fig. 50. Westinghouse Induction Ammeter with Cover Removed

Wattmeters. Wattmeters, or wattless component indicators (which are the same as wattmeters except in the way they are connected in the circuit), can be obtained in either the dynamometer or induction types. In either case, they combine the effects of current and potential coils, which gives watts on the scale. These instruments are made either for single-phase or polyphase circuits. The polyphase instruments really combine two or more single-phase instruments, the moving parts being mounted on a common shaft, so that the reading represents the combined effects of the several elements.

Power Factor Indicators. Power factor indicators are also obtainable in both the dynamometer and induction types. The dynamometer power factor indicator manufactured by the General Electric Company, has two potential coils mounted at an angle and turning in a fixed current coil. The relations of the coil are such that at any power factor the movable potential coils will take up a definite position with regard to the current coil. This depends entirely upon the phase relation, so that the scale can be marked directly in per cents of power factor. The Weston Electrical Instrument Company also makes a dynamometer type power factor indicator built along similar lines.

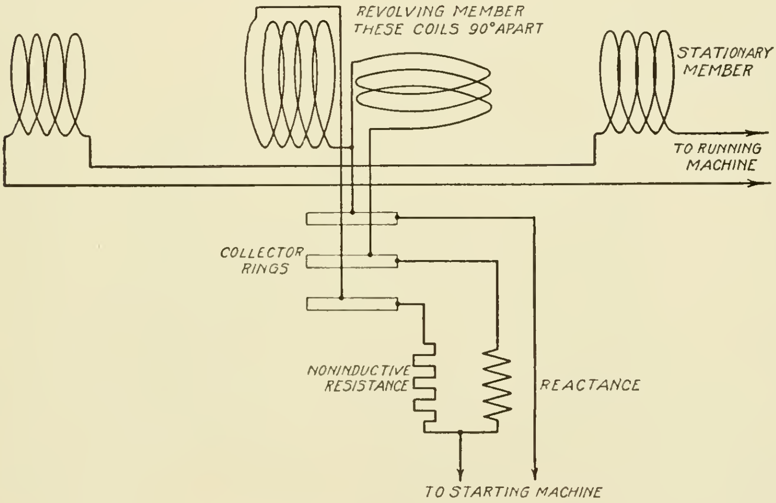


Fig. 51. Wiring Diagram Showing Internal Connections of Synchronizer

The Westinghouse power factor indicator has two current coils set at an angle, which produce a rotating field. Within this rotating field is placed a vane magnetized by a potential coil. This vane tries to place itself in that position where the zero of its own field will be simultaneous with the zero of the rotating field. In other words, the pointer will take up a different position for every change in phase relation between current and potential.

Frequency Indicator. The General Electric frequency indicator has two coils on the moving element, one having a reactance in series and one having a noninductive resistance in series. A fixed coil is connected in series with the other two which are in parallel, and the whole combination is connected across the line. Since one circuit of the armature is inductive and one is noninductive, the frequency will determine the relation of the currents in the two circuits, and therefore the pointer will move with each change in frequency.

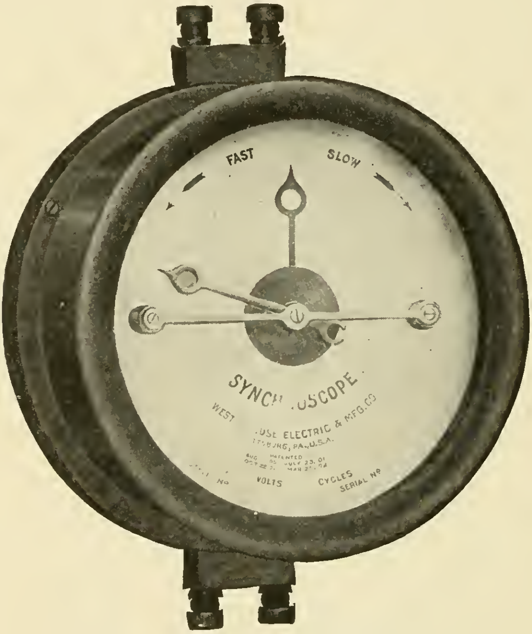


Fig. 52. Westinghouse Synchroscope
Courtesy of Westinghouse Electric and Manufacturing Company

The Westinghouse frequency indicators consist of two induction voltmeter elements connected to act in opposition. One of these elements has a noninductive resistance in series, and the other has a reactance in series. Thus, the frequency determines the relative torque of the two elements and the position of the pointer.

Synchronizer. The synchronizer made by the General Electric Company is similar in its construction to the frequency indicator. The two-coil armature, with its reactance and resistance circuits, is connected to the machine being started, and the stationary coil is connected to the buses or to the running machine, Fig. 51. If the two machines are running at different frequencies, the instrument will act as a motor and the armature will revolve. As soon as the frequencies become the same, the armature will stop. There is also but one position possible for the armature when the circuits bear the same phase relation. Thus, the instrument indicates when the two machines are operating at the same frequency and also when they bear the same phase relation. Also, the speed at which the pointer revolves is a measure of the difference in frequency of the two machines.

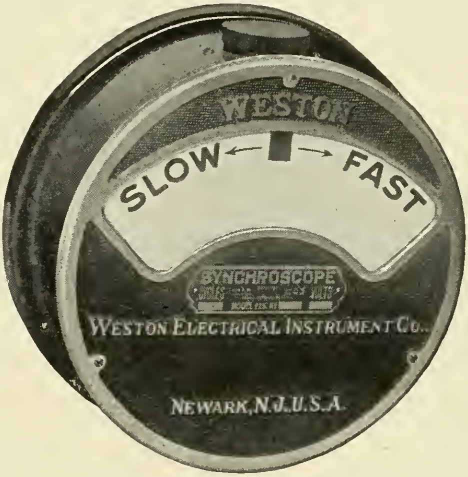


Fig. 53. Weston Synchroscope
Courtesy of Weston Electrical Instrument Company

The Weston synchroscope is built on the dynamometer principle. The pointer is inside the case and moves back of a semi-transparent glass scale. A lamp is mounted back of this scale and connected to transformers which in turn are connected to the two machines being paralleled, so that the lamp is bright only when the machines are in phase. The moving coil of the movement is

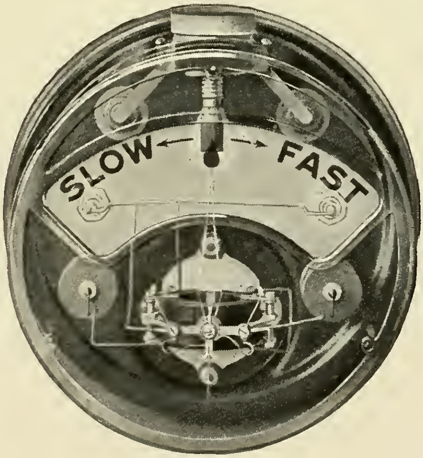


Fig. 54. Weston Synchroscope, Showing Internal Construction

connected to the starting machine through a condenser. The fixed coil is connected to the bus or to the running machine. A spring opposes the movement of the rotating coil. This coil tries to place itself parallel to the fixed coil, and brings the pointer back of the glass both when the machines are in phase and when they are 180 degrees out of phase. Since the pointer may be seen only when the lamp is lighted, which occurs when machines are in phase, the pointer is visible only when the machines are at or near synchronism.

The Westinghouse synchroscope is built the same as the power factor indicator, except that the two elements, instead of being current and potential windings, are both potential windings. One of these is connected to each of the circuits to be synchronized. The operation is then similar to that in other synchroscopes.

Fig. 52 shows a Westinghouse synchronizer, while Figs. 53 and 54 show two views of one made by the Weston Company.

Ground Detector. Ground detectors are used now less than a few years ago, but are still manufactured by some companies. Voltmeters or lamps are always used for the lower voltages. The instruments for higher voltages are adaptations of the electrostatic voltmeter. Fixed and movable vanes are so mounted in the instrument that the vanes are repelled by each other, and the pointer takes up a position representing the condition in the circuit. One terminal is grounded, so that a ground on the system is immediately indicated by the pointer. The position of the pointer indicates the severity of the ground. These instruments are connected to the lines directly in some cases, and in other cases through condensers.

Curve=Drawing Instruments. Curve-drawing instruments are made for alternating-current circuits, as ammeters, voltmeters, wattmeters, power factor indicators, and frequency indicators. They are similar in operation to the indicating instruments and similar in form to the direct-current curve-drawing instruments.

INSTRUMENT TRANSFORMERS

General Requirements. In low voltage circuits it is often necessary to use current transformers in order not to carry the large currents generated into the switchboard instruments or oil switch trip coils. Potential transformers are also used for some purposes even on circuits as low as 240 volts. In the higher voltages, that is, 2300 volts and above, it has become almost universal practice to use both current and potential transformers.

Within the whole range of alternating voltages in commercial use, instrument transformers are found in a majority of cases. These transformers, in order to give accurate readings on the instruments to which they are connected, must have very closely the same ratio between primary and secondary windings under all conditions. The ratios must not be affected by changes in the secondary load nor by changes in the primary current. The ratio of the ordinary transformer used for power purposes varies through wide limits under both these conditions, and the design of instrument transformers must be considerably different to improve the results. When we consider that the instruments connected to the transformers must indicate within, say, two per cent of the actual conditions in the circuit and that these instruments themselves have some inaccuracies, it will be seen that there can not be much error in the transformers.

Potential Transformers. In potential transformers, the variation of the quotient of true ratio divided by marked ratio between no load on the secondary and full load on the secondary may be only a fraction of one per cent in a well-designed transformer. This will vary somewhat with the power factor of the secondary load. The transformer must also be designed so that the secondary current is as nearly as possible in phase with the primary current under all conditions of load.

Current Transformers. In current transformers, as in potential transformers, the quotient of true ratio divided by marked ratio must not vary more than a fraction of one per cent, and the angle between primary and secondary current must be very small. These considerations are all in addition to the question of heating, which must be considered the same as for all other electrical apparatus.

The question of loading for current transformers is one that is important. However, since each manufacturer uses a different design, this matter must usually be left to him. Engineers generally require that the manufacturer make certain accuracy guarantees on the instrument and meters, including their transformers. It should be remembered that a cheap transformer means a poor one, and that a poor transformer means that the indications of the switchboard instruments are of little or no value.

SWITCHES

LEVER TYPE

Lever or knife switches are the ones most familiar to those connected with electrical work, but there are many forms and modifications which have been developed for various uses.

Plain Knife Switch. *Direct Control.* Plain lever switches mounted on the front of the switchboard are used for all low voltage direct-current and alternating-current circuits. They should be well constructed in order to give them a long life, and should be so proportioned that the heating under load will not be excessive.

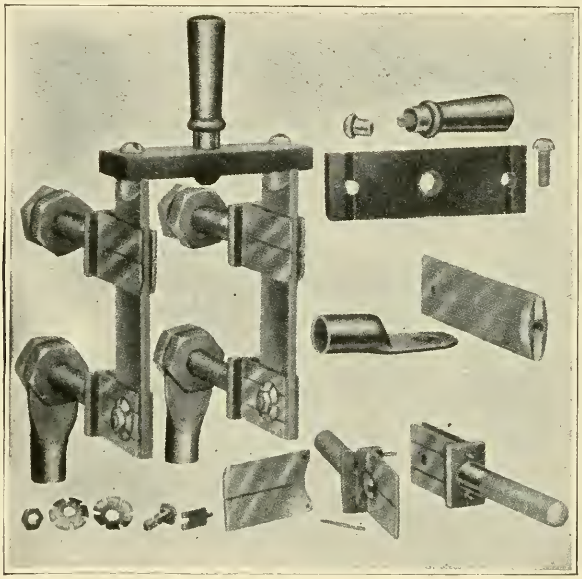


Fig. 55. Exploded View of Double-Pole Lever Switch
Courtesy of General Electric Company

Fig. 55 shows an exploded view of a double-pole lever switch. Some of the points of advantage claimed for this switch will show what care must be used in the design of this class of apparatus:

They are in accordance with the requirements of the National Board of Fire Underwriters;

They are made from the highest grade Lake copper—98 per cent conductivity;

The contact surfaces are machined true, adjusted to gauge after mounting, and tested;

They will carry their full rated current continuously without any part having a temperature rise of more than 28° C. above an atmospheric temperature of 25° C.

Slots are milled in the under side of the crossbars on all single-blade switches, and a tongue on the blade fits into the slot so it can not turn;

Blades are secured in the hinge clips by large one-piece hinge bolts with nut and phosphor bronze spring washers on each side. After the nut is adjusted the end of the bolt is spun over, so that the nut can not wear loose. The springs compensate for all wear in the blades;

Clips are pinned and sweated into specially formed slots in the clip blocks so as to obtain maximum contact;

Steel blade stops are inserted in the clip blocks between the blades but not touching them, and hence, not affecting adjustment or flexibility;

Clip block and studs are forged of hard copper in one piece, and dowel pins are inserted in the under side, which, fitting into holes in the panel, prevent turning of the studs;

Studs of any length are made in one piece, thus saving joints;

Terminals are made from pure drawn copper tubing tinned inside to facilitate sweating in wires or cables;

Blades are forged and machined from hard drawn copper in one piece with the head to which the crossbar is attached;

Crossbars are made of black fiber and fastened to the blades with screws;

Handles are made of hardwood finished in black enamel. The studs are secured so that they can not work loose.

It will be seen that, even in so simple a device as a lever switch, the greatest care must be used to get apparatus that will give service.

In very large capacities, lever switches are often made with laminated studs instead of round ones. In this case, the bars used for connections can be slipped between the laminations and bolted. The greatest care must be used to see that contact is perfect over the whole surface of the laminations. Usually they are made long enough to allow a considerable space between the end of the bar and the end of the slot, since this allows enough spring to insure good contact.

Remote Control. Plain lever switches are now being made for some classes of work for remote control. A number of theaters have installed switchboards in which the front of the panels carries no live parts whatever. In such cases, the switches are mounted on separate panels back of the board and operated by remote control hand mechanisms.

Quick Break Switch. Where switches must break large currents or currents at higher voltages, they are made quick break. In the quick break switch, a follower blade is hinged to the main blade above the main hinge clip and extends up through the front contact clips. It is usually secured against the main blade by a spring. When the blade is opened friction holds the follower blade in the clips until the main blade is some distance from the clips. The follower then carries the current, and when it finally leaves the clips, the springs cause it to move very rapidly so that the arc is quickly broken.

Starting Switch. *Direct-Current.* The direct-current starting switches, when mounted on switchboards, usually consist of a long blade and a number of contact clips and studs, the blade making contact with these successively as it is moved toward the main clips. The intermediate clips are attached to the points of the starting rheostat. In Fig. 10 is shown such a starting switch. This particular switch was arranged so that a full swing of the handle moved the blade only one point and it was necessary to move the handle with a pumping motion in order to make all the points come into contact. This prevents the operator from making a mistake and throwing the switch all the way in without giving the motor time to start.

Alternating-Current. Alternating-current starting switches of the lever type are used a great deal for rotary converters. They are similar to the plain lever switches, except that arcing tips are provided and the handles are weighted to facilitate quick operation.

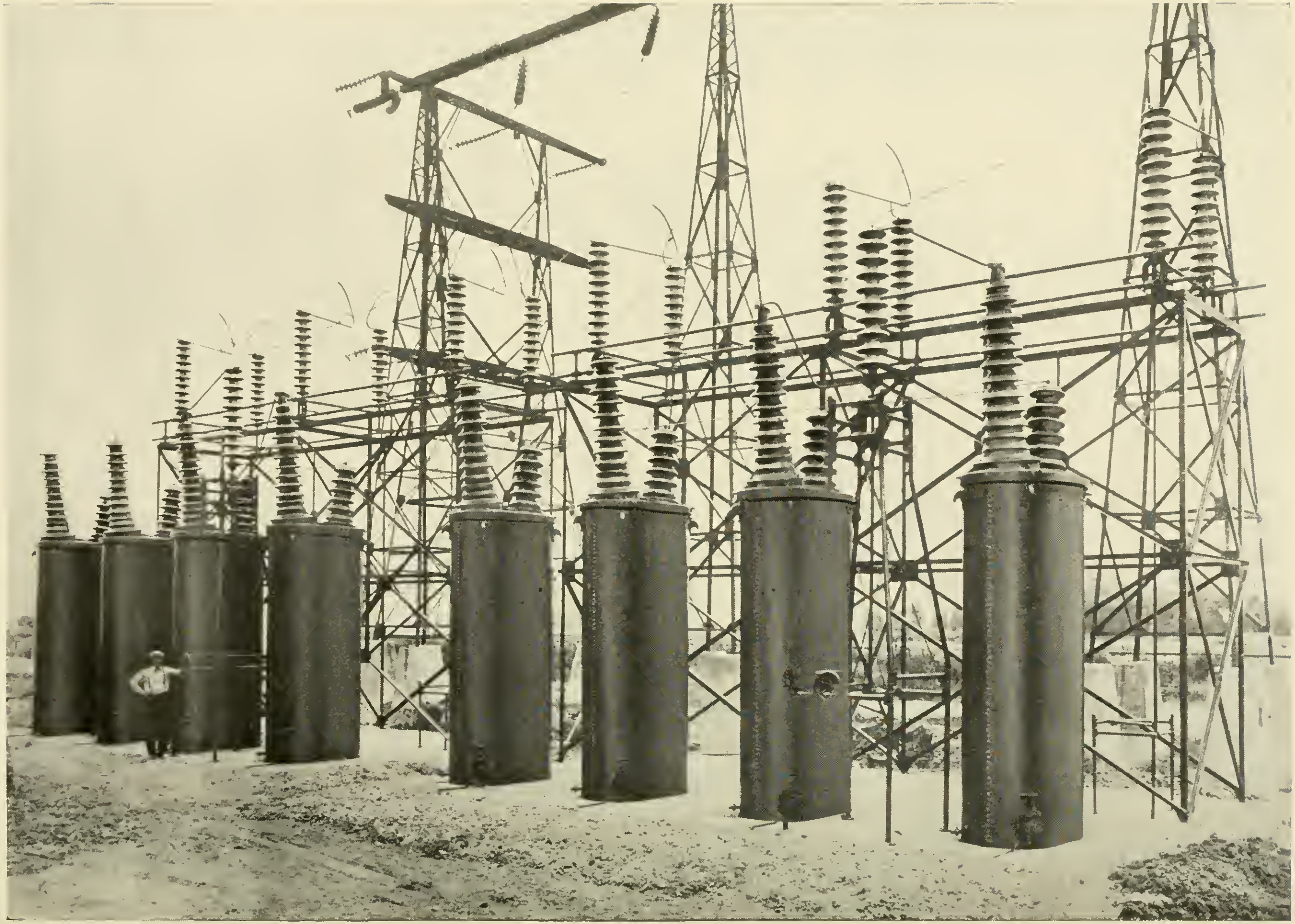
Field Switch. Field switches are also similar to plain lever switches, but are provided with arcing tips and with an auxiliary contact for connecting in a discharge resistance. Another form has the handle attached to the blade by means of a spring. When the handle is pulled down, the spring is tightened until it finally opens the switch with a snap. These switches are also provided with arcing tips and discharge resistance clips.

BRUSH TYPE

Brush type switches are also built for hand operation. They have the advantage of requiring less power to operate than lever switches, so that when the amount of current to be handled is very great and the switch is correspondingly large, they are often used.

ELECTRICALLY=OPERATED TYPE

Solenoid. It is often necessary to operate switches electrically, either because of the size necessary to carry large currents or because



140,000-VOLT ALUMINUM LIGHTNING ARRESTER AT ZILWAUKEE, AU SABLE ELECTRIC COMPANY

Courtesy of General Electric Company

the switch must be placed at some distance from the panel. These switches may be operated either by a solenoid or by a motor. They usually take the form of a brush with auxiliary arcing contacts. If solenoid-operated, the solenoid is often built on the same frame with the switch. Such switches have become very popular for field switches in large stations, and when so used are fitted with discharge resistance clips.

Motor. Motor-operated switches are usually more expensive than those operated by solenoid and are not used to so great an extent. They may be made as plain switches or used in connection with circuit breakers. One such combination includes a switch and a circuit breaker operated by the same motor, but arranged so that the circuit breaker is always closed first and the switch afterward. The circuit breaker is also free to trip if the switch is closed on trouble.

OIL SWITCHES

Importance of Good Design. Oil switches are so universally used on alternating-current circuits that their proper design has been studied very thoroughly by several manufacturers. Merely placing certain contacts in a tank of oil, and attaching terminals for leading the current in and out, and providing a mechanism for operating the contacts, does not make an oil switch. The leads may be properly insulated and all parts may be ample for carrying the current, and still the switch may not be able to rupture successfully the amount of power represented by rated volts and amperes of the switch, under short circuit conditions. Alternating-current generators are able to produce power far in excess of their normal capacity for short periods. Any oil switch connected to the buses fed by such generators must be able to rupture the entire energy delivered to the buses by those generators, under short circuit conditions as well as under normal conditions.

There are many points which enter into the proper design of these switches, and each manufacturer has produced switches which are claimed to be satisfactory and able to rupture circuits under all conditions. All such claims should necessarily be backed by a large amount of experience and tests under the most unfavorable conditions. Guarantees should always be based on ability to rupture a definite number of kilovolt amperes in rated capacity of generators. It is not possible to use the actual short circuit capacity of the generators, since the one who purchases switches usually can not know what the generators are capable of producing under such conditions. It should always be remembered that tests offered by manufacturers, as showing what switches will do, should be with generators of high short circuit capacity, such as high speed low reactance steam turbine-driven machines.

The sustained short circuit capacity of generators is very much less than the instantaneous value, so that switches can be given a higher rating if operated by time limit relays which will prevent their opening until after the first great surge of current.

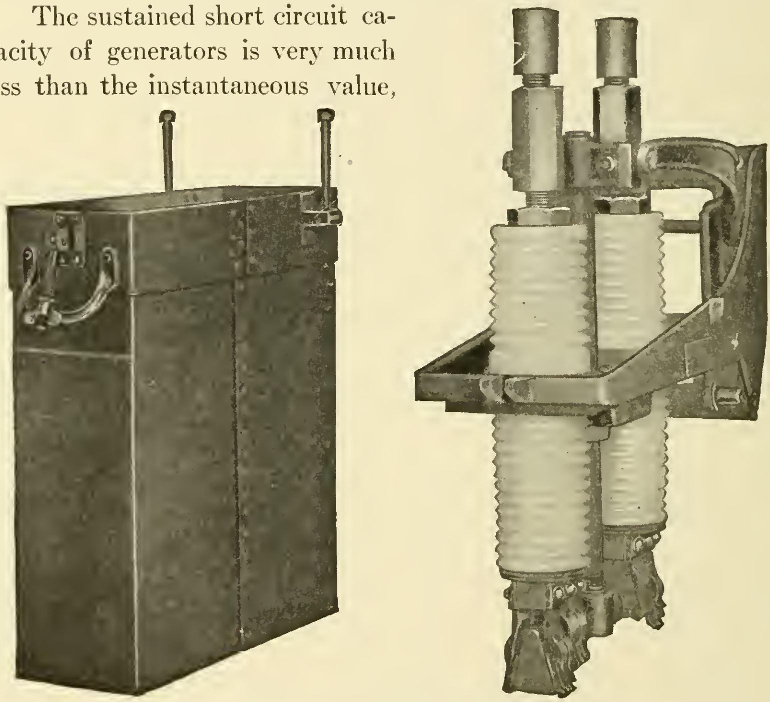


Fig. 56. General Type of Oil Switch with Cover Removed
Courtesy of General Electric Company

Types. *Low Voltage.* Oil switches are built for use on circuits ranging in voltage from 600 volts to 150,000 volts. Those used on the lower voltages usually consist of a frame which carries all the operating parts and to which is attached an oil tank enclosing the contacts. The studs are passed into the switch through proper insulators, and the moving contacts are also insulated from the operating mechanism. The tanks may be detached from the frame and dropped down, thus exposing all working parts for inspection or repairs and making the oil accessible for renewal.

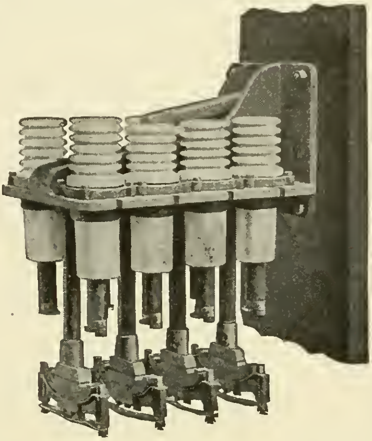


Fig. 57. Westinghouse Type of Oil Circuit Breaker
Courtesy of Westinghouse Electric and Manufacturing Company

Figs. 56 and 57 show oil switches of this type as manufactured by the General Electric Company and the Westinghouse Company, respectively. The first is a single-pole single-throw 15,000-volt 300-ampere switch. The second is a four-pole single-throw 15,000-volt 300-ampere switch. Both are shown with the tanks removed in order to show the contacts, etc. The operating mechanisms consist of a system of levers arranged to give an upward motion of the contacts for closing. Both these switches open by gravity when tripped.

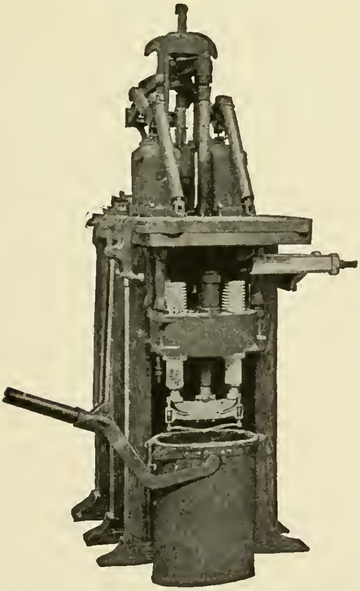


Fig. 58. Oil Circuit Breaker with Solenoid-Operating Mechanism
Courtesy of Westinghouse Electric and Manufacturing Company

Solenoid-Operated. Fig. 58 shows another similar oil switch for cell mounting and with a solenoid-operating mechanism. The other switches illustrated can also be adapted to solenoid operation in a slightly different way.

High Capacity. The H-3 and H-6 oil switches made by the General Electric Company are for high capacity. They are different from the ones illustrated in that a separate oil tank or pot is provided for each break, or two pots per pole of the switch. Fig. 59 shows one of these switches. The pots are mounted one back of the other in compartments, the contacts move downward to close the switch and are operated by a motor mechanism on top of the cell. This mechanism does not operate the switch directly but through large coil springs which are compressed by the motor. The motion, therefore, is very quick and is not dependent upon the speed of the motor. The pots are live and only arcing contacts are under oil except in small sizes. All large switches have the main contacts outside the pots, but the arc is broken under the oil.

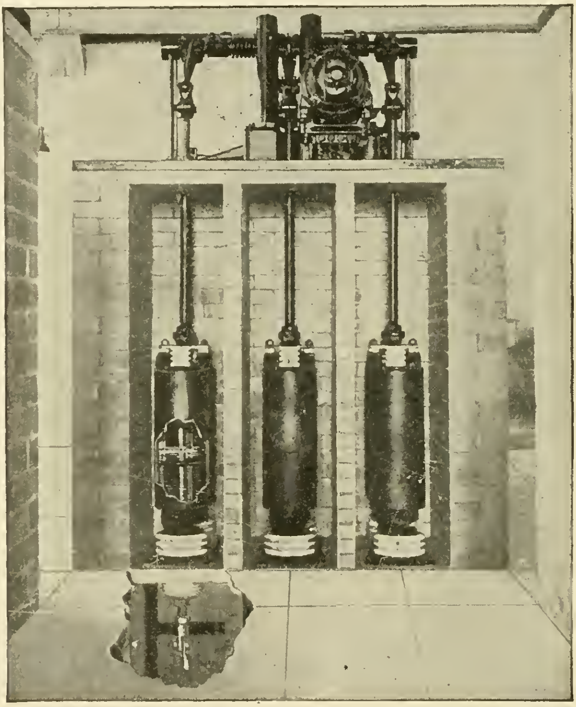


Fig. 59. General Electric Triple-Pole Single-Throw 15,000-Volt Oil Break Switch Operated by Motor
Courtesy of General Electric Company

Pneumatically-Operated. For very high voltages, switches similar in action to the ones in Figs. 56 and 57 are used, except that the tanks, being large and heavy, are set directly on the floor. Fig. 60 shows such a switch as manufactured by the General Electric Company. This illustrates a switch with a pneumatic operating mechanism.

All oil switches should be designed with as much care as that given to any electrical apparatus. Such points as mentioned under lever switches should be considered. The heating should be low, the mechanical arrangement of parts should be good, and the general arrangement of parts should be such as to give great strength and long life. These points should all be considered in addition to the manufacturer's guarantee as to rupturing capacity.

Methods of Operation. Oil switches may be operated in a number of ways. They may be operated by hand, either at the board or remote from it. Remote control mechanisms usually consist of a lever at the board and a system of bell cranks with connecting links of gas pipe. They are somewhat flexible but limited as to distance and as to position in some cases. Electrically-operated switches can be placed anywhere within the limits of the available operating voltage. Solenoids are generally used for operating oil switches and have proved very satisfactory. A constant source of direct current must be provided for their operation. Motor-operating mechanisms can be made for either alternating current or direct current, although the direct-current motor is more often used.

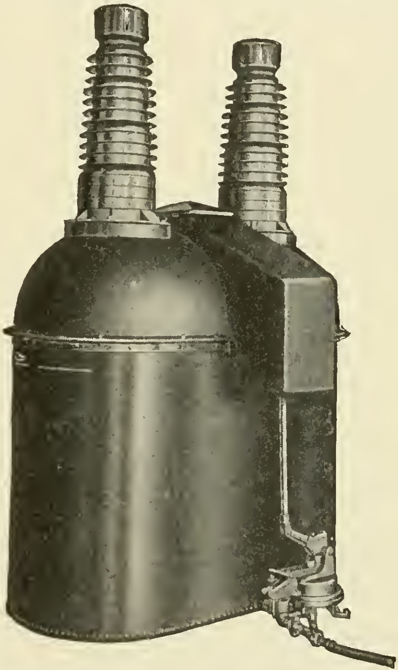


Fig. 60. Single-Pole 110,000-Volt Oil Break Switch, Pneumatically-Operated
Courtesy of General Electric Company

Attachments. Oil switches can be supplied with a large number of attachments or auxiliaries for producing certain results under certain conditions. Low voltage coils will trip the switch when the voltage falls below a predetermined value. Shunt trips are for tripping from a constant potential source. They can be tripped from a number of conditions, such as reversal of currents, overload, underload, or reversal of phase by means of the proper relays. These relays and their actions are discussed under another section.

DISCONNECTING SWITCHES

Design. Disconnecting switches are in most cases only modifications of the ordinary lever switch. They must, of course, be insulated for the voltage on which they are to be used. For 2300 volts the insulation is usually marble. For the higher voltages, up to 150,000 volts, porcelain insulators are used. For the lower voltages the blades are straight solid bars, but for higher voltages the distance necessary between the insulators is so great that a solid blade is usually weak mechanically. Sometimes a tubular form is adopted, the ends being flattened to fit into the clips. Another method of gaining strength is to make the blade of two pieces riveted together at the upper end and spread apart to form two separate blades at the lower end. Braces can be inserted at intervals along these two blades, and a truss is thus formed which has great mechanical strength and rigidity.

Locking Device. When short circuits occur on large systems, the disconnecting switches are often thrown out of the clips, thus opening the circuit and often doing great damage. Locks should always be provided for the disconnecting switches in such stations. They should be of such a character as to lock automatically when the switch is closed and should not require much time or effort to release when it is desired to open a switch. They should be as strong as the switch itself, so that there will be no danger of a mechanical failure.

CONTROL SWITCHES

General Requirements. Control switches are small switches of numerous forms, used for throwing current on the various electrically-operated devices accompanying the switchboard. They are not usually called upon to carry much current, but should be strong and certain of action, since a great deal depends upon them. They should, when used for oil switches, indicate clearly the last previous operation. They should be so marked that there can be no doubt as to the positions for producing certain results. If of the spring return type, they should return quickly and positively to the normal position as soon as released. They should be of such a substantial nature that there is little possibility of their getting out of alignment or failing to make proper contact.

Indicating Lamps. Indicating lamps are often furnished with switches of this kind. They are mounted in receptacles which are fastened to the rear of the panels, and the lamp projects into a hole in the panel which is covered with a bull's-eye. These bull's-eyes are often fitted with a prism across the face, which reflects the light so that it is visible from either side as well as from the front. Proper ventilating holes should be provided since the lamp generates considerable heat.

CIRCUIT BREAKERS

Circuit breaker design has changed a good deal, and many forms and many principles of operation have been tried in a comparatively few years. At the present time, there are certain points which have been adopted by practically all manufacturers except for certain special classes of service. The carbon secondary break and the laminated brush for carrying the main current, are features found in one form or another in very nearly all circuit breakers.

General Requirements. Many of the same points must be considered as in lever switches. The heating is always the first thing considered. The breaker should be able to carry its full rated current continuously with a temperature rise in any part of only about 30° C. In the past, it has been the practice of some engineers to specify the current density in the various parts. The only idea in limiting the current density is to insure proper operation under all conditions without undue rise in temperature. Obviously, the more direct way would be to specify the temperature rise. This also gives the designer more freedom in his work and allows him to work for mechanical strength and simplicity, and to get proper temperatures in any way he wants without regard to the density at any point.

Ease of operation is another very important point where circuit breakers must be hand-operated, and the manufacturer who can make a device which operates positively and easily without a complicated or expensive mechanism, has many points in his favor.

Circuit breakers must open positively and quickly when tripped and must do it without too much jar, which might injure instruments or even crack the panels. Gravity should be the operating force in opening, and it is much better to do away with springs to assist in the opening operation.

Circuit breakers should, as far as possible, be self-aligning, so that no special training is necessary in order to assemble them on the panels. They should be built so that any attachments for obtaining operation under various conditions in the circuit can be added without change in the breaker or return to the manufacturer.

Method of Operation. *Hand.* Hand-operated circuit breakers may be built either for direct or remote control. Direct control is generally used unless the voltage is so high as to make it necessary to get the circuit breaker out of reach of the operator.

Electrical. Electrically-operated breakers are very widely used. They may be operated by motor or solenoid. The solenoid mechanism is very much simpler and is also less expensive. In some cases, breakers of capacities up to 4000 amperes are built with the solenoid casing made a part of the circuit breaker frame. This makes a very compact and durable device and one occupying a minimum amount of space. Motor-operated mechanisms are often used when several breakers are to be operated simultaneously. They close slowly and require much more care and attention than solenoid-operated breakers.

Pneumatic. There are many cases where a constant source of electrical supply is not available or where for other reasons it is not desirable to use electricity for operating the breakers. In some such cases, they have been operated by a pneumatic mechanism. These mechanisms are similar to the solenoids ordinarily used, except that an air diaphragm or air cylinder takes the place of the solenoid, and a valve similar to the ordinary engineer's valve on a locomotive replaces the control switch.

Attachments. *Time Limit.* Many attachments are available for circuit breakers by which they may be made to operate under almost any condition in the circuit. They may be made time limit, either inverse where the time element decreases as the overload increases, or definite where the time element is independent of the current flowing.

The two most common methods for obtaining a delay in operation are by air bellows and by disks in oil. In the first, the action of the plunger which trips the breaker is against a small air bellows of special design. This bellows is fitted with an adjustable valve so that the rate of escape of air can be regulated. Thus, the time necessary to raise the plunger far enough to trip the breaker can be regulated. Since the force applied to the plunger determines the pressure in the bellows, and therefore the time of operation, the device will operate in inverse proportion to the current. For definite time, the plunger compresses a spring which in turn acts on the bellows. The spring is always fully compressed when the device operates, so that the pressure applied to the bellows is always the same and the time element is therefore definite.

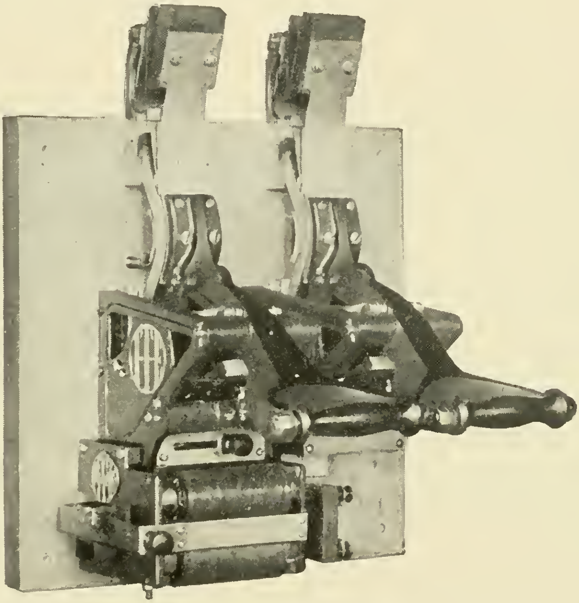


Fig. 61. Double-Pole Overload and Reverse-Current Circuit Breaker
Courtesy of the Cutter Company

In the disk time limit device, the action depends on the fact that two surfaces coated with oil and pressed together can not be separated immediately. With the same force applied, the two surfaces will stick together for a considerable time and then suddenly let go, allowing the trip to work.

Shunt Trip. Shunt trip coils are merely small solenoids, arranged to operate a tripping arm. They may be used to trip a breaker from some distant point, for interlocking purposes, or many other uses.

Low Voltage and Reverse Current. Low voltage release coils, as the name implies, trip the breaker when the voltage falls below a certain point. Reverse-current attachments are made in two ways: In one, there are two coils acting on a common plunger. One is connected across the source of current and one in series with the line. When current flows in the usual direction, the two coils oppose each other, and the plunger does not move. If, however, the current reverses, then both act together, and the breaker is tripped. The other reverse-current device is really a small motor with its armature across the lines and its field in series with the line. Normally the armature, which carries a small contact arm, stands against a stop, but when the current reverses, the armature reverses, and the contact arm swings over, closing a circuit, which trips the circuit breaker.

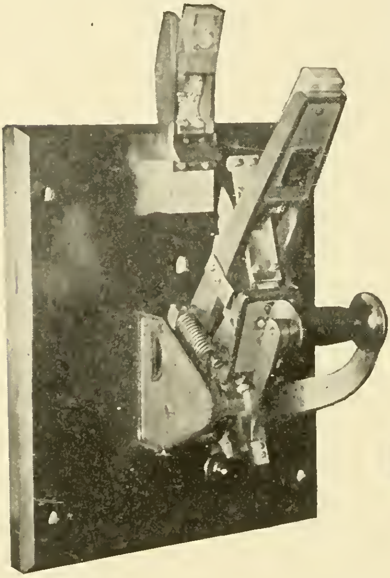


Fig. 62. 2000-Ampere Hand-Operated Circuit Breaker
Courtesy of Westinghouse Electric and Manufacturing Company

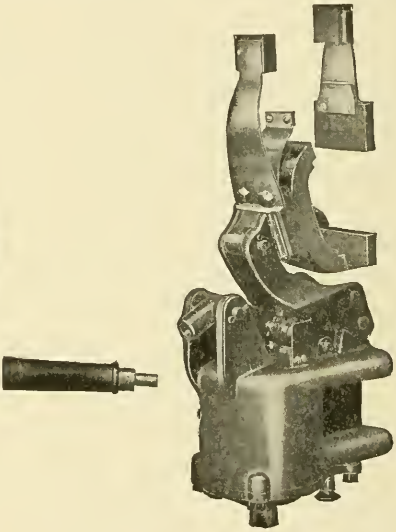


Fig. 63. Solenoid-Operated Circuit Breaker
Courtesy of General Electric Company

Underload. In underload attachments, the current flowing holds the tripping plunger away from the tripping lever, and when the current falls below a certain point and no longer exerts enough force to do this, the plunger drops and trips the breaker.

Reverse Phase. Reverse-phase protection, which is used somewhat on alternating-current elevator motors, is obtained by a device which is in principle an induction motor. This device usually takes the form of a relay which operates on a shunt trip or low voltage release. As with the induction motor, if one phase is reversed, the motion or tendency toward motion is reversed, and the relay operates, closing the circuit to the tripping device.

Automatic oil switches are sometimes called circuit breakers.

Fig. 61 shows a double-pole overload and reverse-current circuit breaker manufactured by the Cutter Company; Fig. 62 shows a Westinghouse overload circuit breaker; Fig. 63 shows a General Electric solenoid-operated circuit breaker.

SWITCHBOARD RELAYS

Direct=Current Type. *Overload.* Overload protection on direct-current circuits is usually taken care of by a tripping device attached directly to the circuit breaker, but in some cases it is not convenient to do this, and a relay must be used. These relays usually consist of a coil of wire or copper bar of a size sufficient to carry the total current of the circuit. Inside this coil is a plunger which carries contacts used to close an auxiliary tripping circuit. When current is flowing in the coil, the plunger will tend to rise until it stands in the middle of the coil. If it is dropped down, more current will be necessary to lift it to that position. Thus, the plunger can be dropped down to give any calibration within certain limits, and the auxiliary contacts will be closed only when the current in the coil reaches a value sufficient to lift the plunger.

Reverse Current. Two types of reverse-current relays are used on direct-current circuits. One scheme is similar to the reverse-current attachment used on circuit breakers. A potential coil and a current coil oppose each other under normal conditions so that the plunger does not move. When the current reverses the two coils act together and the plunger is immediately raised and closes the contacts. The other relay consists of a small motor, the armature of which is connected across the line while the field is in series with the line. Normally the armature swings against a stop, but when the current reverses it swings in the other direction and makes a contact which may be used to trip the circuit breaker. This form is sometimes modified to have a permanent magnet field. The armature then carries a shunted portion of the current.

Differential. Differential or balance relays are used on three-wire systems and operate when the un-balancing becomes excessive. Two coils, one connected from each outside wire to the neutral, are wound to oppose each other. When the unbalancing becomes excessive, one will overcome the other and swing the contact arm to one side or the other, causing the circuit breakers to open or causing an alarm bell to ring.

Signal. Signal relays are used in connection with electrically-operated switches. They consist of a solenoid with a plunger and contacts. The contacts are arranged to hold the plunger in contact until it is pulled down. They are connected in circuit, so that if any switch operates automatically, the signal relay will operate, throwing current on a bell and thus calling the operator. The bell will continue to ring until the operator pulls down the plunger of the signal relay.

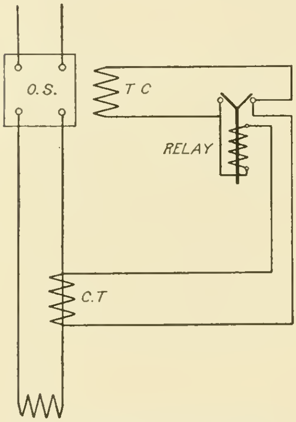


Fig. 64. Diagram Showing Operation of Single-Pole Overload Relay

Control. Control relays are simply small solenoids operating contacts which in turn throw current on the operating coils of switches or circuit breakers. They are used merely to relieve the control switches from carrying the full control current.

Alternating-Current Type. *Overload.* In alternating current the relays most used are the overload relays. These are similar in construction to the direct-current relays, except that the plungers must be made of laminated iron. They are made for connection in series with the lines, but are nearly always used on the secondaries of current transformers, Fig. 64. These relays may be instantaneous, inverse time limit, or definite time limit. The time limit relays are usually equipped with a bellows with proper relief valve for obtaining the time element. In inverse time limit relays the plunger acts directly on the bellows. Thus, as the overload increases pressure on the bellows increases, and the air escapes faster, giving the inverse relation of current and time. In the definite time limit relay, the plunger compresses a spring which in turn acts on the bellows.

Since the pressure of the spring is always the same, the time is always the same. Different time settings can be obtained by adjusting the valve on the bellows. Current settings are obtained by adjusting the plunger up and down in the solenoid. When such relays are used in series with very high voltage circuits they must be properly insulated. They are usually mounted on a porcelain insulator, and the plunger, instead of acting directly on the contacts, operates a small switch through an insulating rod.

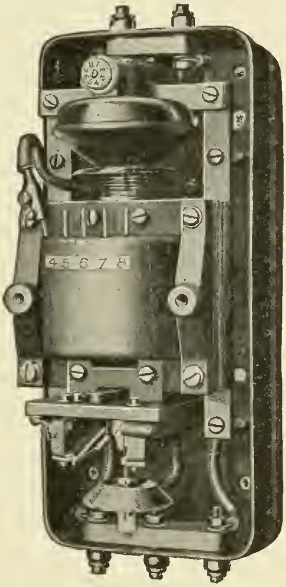


Fig. 65. Alternating-Current Time Limit Overload Relay
Courtesy of Westinghouse Electric and Manufacturing Company

Underload. Underload relays are similar to overload relays, except that they are designed so that the normal current holds the plunger up, and when the current falls below a certain value, the plunger drops, closing the contacts for tripping the switch.

Reverse Current. There are several kinds of reverse-current relays. What is known as the differential reverse-current

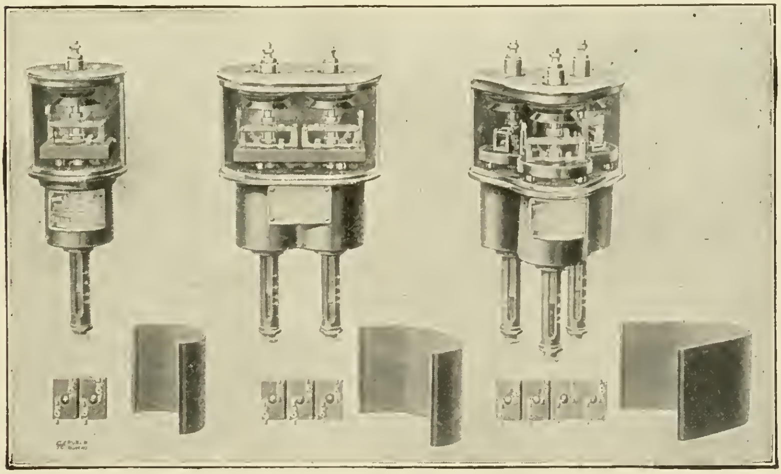


Fig. 66. Time Limit Overload Relays with Covers Removed
Courtesy of General Electric Company

relay is used to protect transformers against trouble in themselves. There are two opposing current coils connected to current transformers on both the low and high tension side of the transformers. The ratios of the current transformers are such as to give the same current in both coils, and connections are such that there is no movement of the plunger under normal conditions. If a short circuit should occur in the transformer and power should be fed from both high and low tension sides, then the two coils would act together, and the plunger would rise and close contacts, which would trip both high and low tension switches.

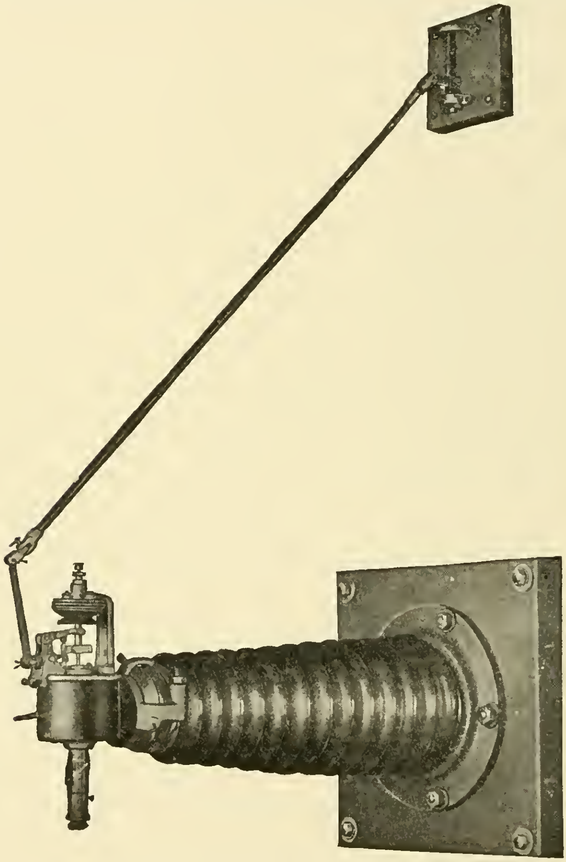


Fig. 67. High Potential Series Relay, Mounted on Post Insulators
Courtesy of General Electric Company

Another form of relay used for two lines has two current coils and two potential coils per pole. One current and one potential coil are wound opposite each other in the same case, the two plungers are then mechanically interlocked, so that one can go up at a time but not both at once. Thus, if the current in one line reverses, the relay will act, but it will not act on overload.

Another form of reverse-current relay is really a wattmeter. It has a moving potential coil and stationary current coils. When current flows in one direction, the potential coil will swing in one direction, and when it flows in the opposite direction the coil will swing in the other direction. This moving coil carries a contact finger which can be used for closing a tripping circuit.

Reverse Phase. The reverse-phase relay is essentially an induction motor in the form of a solenoid and plunger. The plunger is a tube and is within two coils. With correct phase rotation, the tube tends to move down, and if one phase is reversed, it tends to move up. The upward motion can be used to close contacts for tripping the switches.

Low Voltage. Low voltage relays are arranged to hold the plunger up with normal voltage. When the voltage falls below a certain point, the plunger falls, closing the contacts.

Fig. 65 shows a Westinghouse alternating-current inverse time limit overload relay with the cover removed. Fig. 66 shows similar relays of General Electric manufacture. Fig. 67 shows a General Electric high tension overload relay.

FUSES

While the use of fuses has been largely superseded for some kinds of service, they still have a wide field and offer the cheapest means of protecting electric circuits.

Low Voltage Type. *Enclosed N. E. C. S.* For low voltage circuits, both alternating-current and direct-current, the fuses used for circuits of moderate capacity are usually enclosed National Electric Code Standard fuses. They are made by a large number of manufacturers and are uniform as to form and dimensions. They consist of a fiber tube with ferrules at the ends, and in the larger sizes contact clips attached to the ferrules. The fuse wire is attached to the two ferrules and the tube is filled with a non-arcing compound.

A very small indicating wire is usually brought out of the tube at some point. This wire is in parallel with the main fuse and indicates by its condition whether the main fuse has blown.

Link. Open link fuses are used for capacities above 600 amperes, since the enclosed fuses are not made above that capacity. They consist of links of fuse material which are bolted to the fuse blocks. They are smaller at the middle, so that they will always blow at the same point.

High Voltage Type. *Expulsion.* For higher voltages the fuses must be somewhat modified. Enclosed fuses are used for some purposes even up to as high as 15,000 volts. However, the expulsion type is more often used, and it has been made up to 70,000 volts. In this form the fuse is placed in a tube which is open at one end. At the opposite end the tube is larger, forming an explosion chamber. The fuse is made smaller at this point, so that the break always comes within the explosion chamber. The action is like that of a gun. When the fuse blows, the gases formed increase the pressure in the tube until the remaining part of the fuse and all loose metal are blown out of the opening with great force. This makes a quick opening fuse and one which is very positive in its action. Fig. 68 gives a good idea of this type of fuse as manufactured by the General Electric Company.

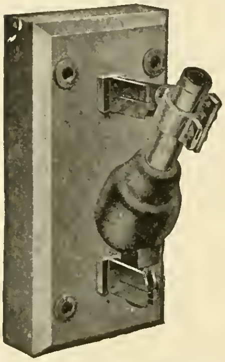
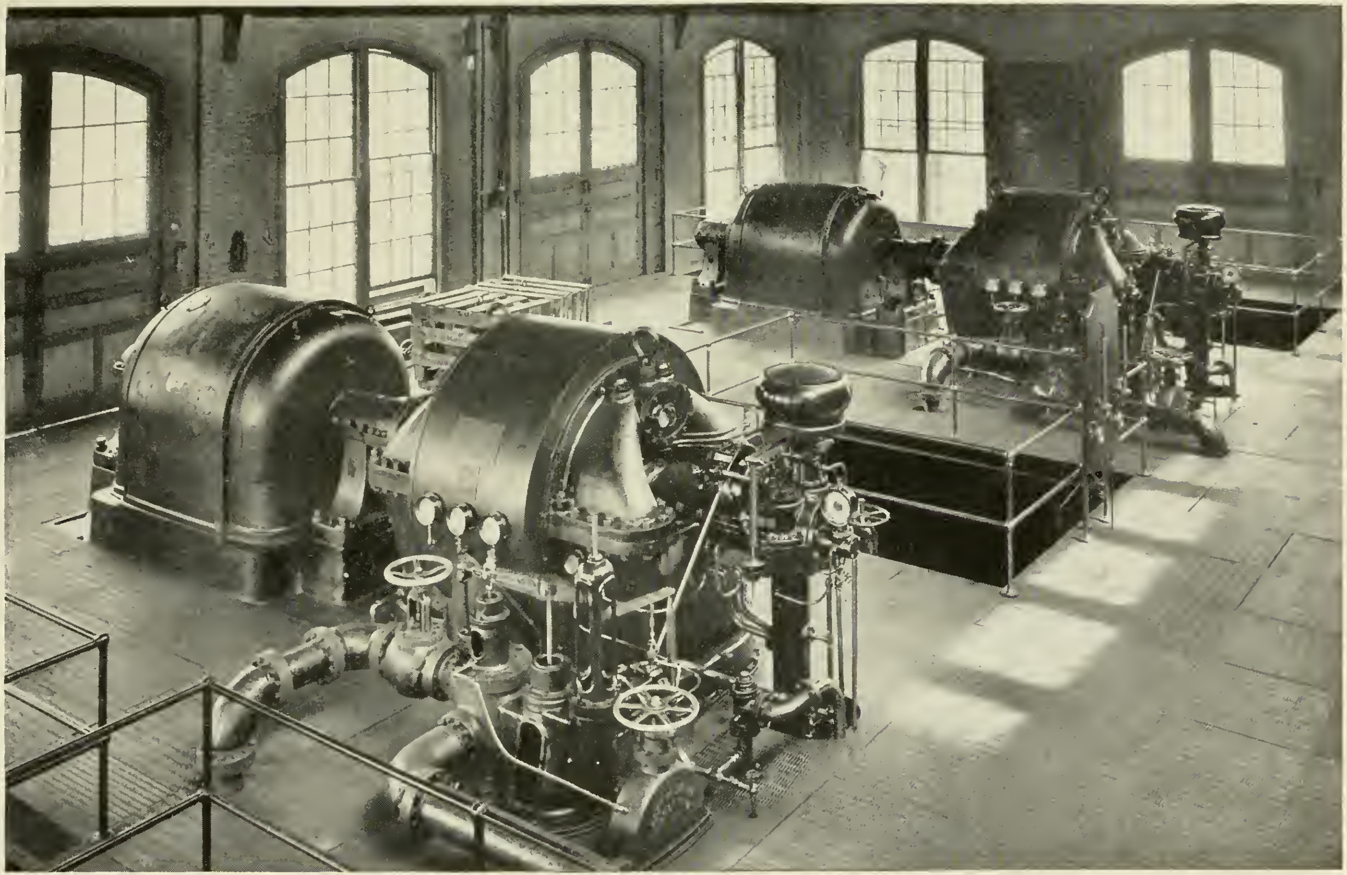


Fig. 68. General Electric Single-Pole Expulsion Fuse Block
Courtesy of General Electric Company

LIGHTNING ARRESTERS

Direct-Current Service. *Magnetic Blowout.* For direct-current service, except arc circuits, there are two or three forms of lightning arresters made. Magnetic blowout arresters consist of a spark gap with a series resistance of carbon. A coil is mounted with the gap and connected so that if current flows across the gap, it will flow through the coil. An iron core is so formed that the magnetic field set up by the coil forces the arc away from the gap, drawing it out until it breaks. These arresters are usually mounted in a porcelain casing with a removable cover.

Multipath. Another form of arrester, known as the multipath arrester, is manufactured, and can also be used on alternating current.



TWO 1875-K.V.A. THREE-PHASE 11,000-VOLT LOW PRESSURE UNITS. INSTALLED FOR THE DUQUESNE LIGHT COMPANY AT RANKIN, PENNSYLVANIA

Courtesy of Westinghouse Machine Company

A thick disk of carborundum is mounted in a case, the line lead attached to one side, and the ground lead to the other. A static discharge will spread itself over the surface of the block in a large number of paths and the discharge will pass to ground.

Aluminum Cell. Aluminum cell arresters are also made for direct-current circuits. Their principle of operation is described under alternating-current arresters. The aluminum cell arrester is being used a great deal for railway service and for relieving underground lines from static charges. They require some attention, but will give better protection than other types.

Alternating-Current Service. *Multigap.* For alternating current circuits, the multigap arrester has been used for a number of years and has given good service. This arrester consists of a number of knurled cylinders of "non-arcing" metal, mounted so that the gaps formed between the cylinders in series are sufficient to insure that the line voltage will not start an arc. Carbon or graphite resistance rods are usually connected so as to shunt some of the gaps, in order to suppress the arc after the lightning discharge has passed.

Another form of the multigap arrester has the series of cylinders mounted inside a tube together with a series resistance. The tube is sealed tight. When a discharge occurs, the gases formed from the arcs between the cylinders have a rectifying effect tending to extinguish the arc at each reversal. Also, the pressure inside the tube is greatly increased, thus assisting in extinguishing the arc. These arresters are weatherproof and are intended for installation on poles for line protection and for protecting individual transformers.

Aluminum Cell. The aluminum cell lightning arrester is a development of the last few years. If two aluminum plates are immersed in a suitable electrolyte and a current is passed through them, a film of hydroxide of aluminum is formed over their surfaces. If voltage is applied to this cell a very small current will flow unless this voltage be increased to what is known as the critical value. At the critical voltage, the film breaks down and allows the current to flow through the cell. The current is then limited only by the resistance of the cell. Commercial arresters of this type have a large number of inverted aluminum cones mounted a fraction of an inch apart. The electrolyte is poured into these cones and partly fills them. The number of cones depends, of course, on the voltage of the system on which the arrester is to be used. The cones are then immersed in a tank of oil. The top cone has a wire attached and carried out through the cover of the tank inside a porcelain insulator. The cones are insulated from each other. These arresters are much better than any other type ever used. They will discharge for long periods, either continuously or intermittently, without damage. They will take care of surges in voltage as well as lightning.

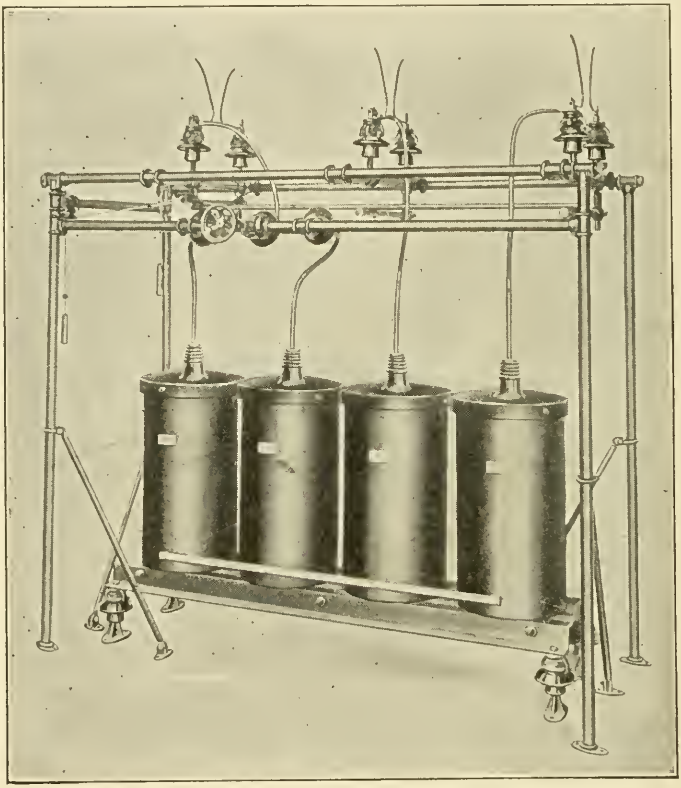


Fig. 69. Aluminum Lightning Arrester for Three-Phase Circuit
Courtesy of General Electric Company

The film on the plates will gradually dissolve if the arresters are left long disconnected from the circuit, and arrangements are always provided for connecting them to the line at intervals to re-form the film. The cells are connected in series with horn gaps, which are adjusted for the particular voltage on which they are to be used.

Horn Type. Lightning arresters installed on arc circuits either alternating-current or direct-current, are usually of the horn type. They consist merely of a pair of horn gaps and a series resistance connected to each line.

Another form sometimes used consists of a pair of lignum-vitae blocks which have charred grooves on their faces. These two faces are placed against each other and electrodes are put at each end. The charred grooves serve as a path to ground for the discharges.

Accessories. *Choke Coils.* Choke coils are nearly always installed with lightning arresters. They consist of coils of wire which offer considerable impedance to high frequency discharges but not to the normal operating frequency. They are inserted in the line between the arrester and the apparatus to be protected and help to make the discharge pass into the arrester rather than into the apparatus.

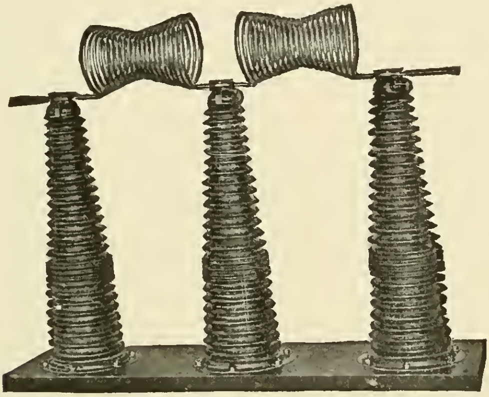


Fig. 70. Choke Coils Used with Lightning Arresters

Horn Gaps. Horn gaps consist of two pieces of copper wire bent into the shape of goat horns and mounted on insulators. When used on aluminum cell arresters they are arranged so that one can be swung around and thus act as a disconnecting switch. They are also arranged to be moved in the other direction to connect the arrester to the line for charging.

Discharge Recorders. Discharge recorders are used with aluminum cell arresters to keep a record of all discharges through the arrester. This is simply a set of spark gaps connected so that discharges either from line to line or from line to ground pass through the gaps. A clock mechanism moves a roll of paper between the gaps, so that the paper is punctured if a discharge occurs. Thus, a record is made of the time of the discharge, and to some extent the holes indicate the severity of the discharge.

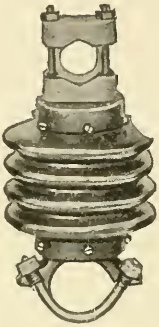


Fig. 71. Busbar Insulator

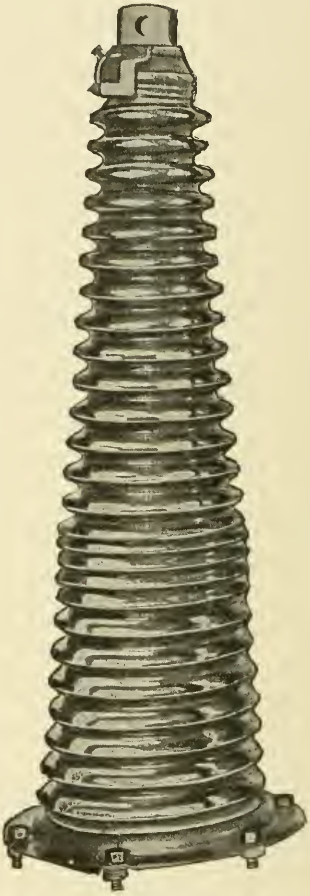


Fig. 72. Busbar Insulator for High Voltage

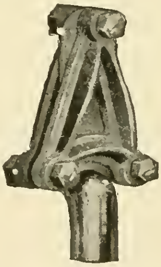


Fig. 73. Busbar Clamp

Charging Ammeter. In order to be sure that arresters are not taking excessive current when being charged, a charging current indicator is often used. A small ammeter is mounted on an insulating handle and fitted with contacts on the end of the handle which can be inserted in jacks on the arrester tank, thus inserting the ammeter in series with the plates and allowing the operator to read the exact charging current.

Fig. 69 shows a General Electric aluminum cell arrester and horn gap for 13,200-volt indoor service. Fig. 70 shows a choke coil of the hourglass type.

MISCELLANEOUS FITTINGS

There are a large number of fittings and appliances used on switchboards which are not included in any of the foregoing sections.

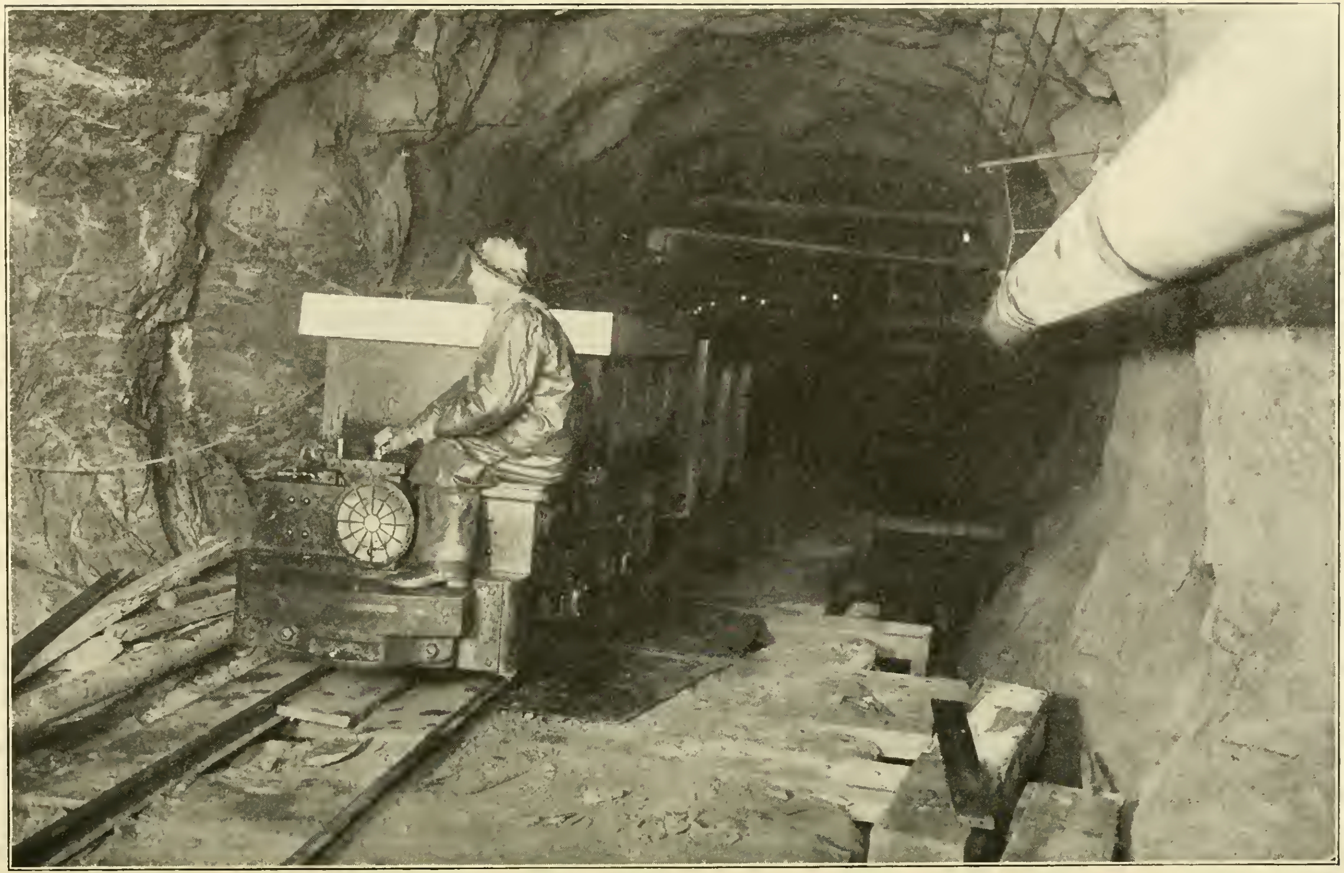
Receptacles and Plugs. A great many connections for voltmeters or other instruments are made by means of receptacles and plugs. The receptacles consist of studs extending through the board at the back and carrying at the other end two receptacles usually divided into leaves which act as springs. These receptacles are flush with the front of the panel or an insulating base, and any number may be assembled together, depending on the connection to be made. The plugs are solid cylinders which fit into the receptacles. They are mounted in a block through which connections are run and to which a handle is attached.

Transfer Switches. Transfer switches are used mostly in the secondaries of current transformers. They consist of a shaft passing through the panel with a handle on the front end and contacts on the other end. Stationary contacts are mounted on the back of the panel. Revolving the shaft causes the contacts to move into various relations, depending on the connections desired.

Busbar Supports. Busbars for low voltages are sometimes carried on slate supports, but for all the higher voltages porcelain supports are used. They are arranged for mounting on pipe framework or on flat surfaces and are placed in any position. Fig. 71 shows one type of busbar insulator for mounting on pipe. Fig. 72 is a busbar insulator for very high voltage.

Clamps. Connections to rectangular copper buses are usually made with clamps. Fig. 73 shows such a clamp. These clamps may be used for attaching cable terminals, as shown, or for attaching copper bars.

All miscellaneous fittings should be the best obtainable, since they will give the least trouble from mechanical or electrical weakness and will be less liable to need repairs.



STORAGE BATTERY LOCOMOTIVE IN OPERATION IN BROOKLYN SECTION OF AQUEDUCT TUNNEL

Courtesy of General Electric Company

STORAGE BATTERIES

Storage or secondary batteries, also called *accumulators*, consist of cells in which a chemical change is brought about by passing an electric current through them, thereby rendering them capable of giving back electrical energy, or *discharging*, until they return to their original chemical condition.

Ordinarily a storage battery consists essentially of two sets of plates suspended in a chemical solution. The plates are of metal or metallic oxide, and the solution is incapable of acting upon them until an electric current is passed from one set of plates to the other. This current decomposes the electrolyte, one of its ions or constituents going to one set of plates and the remaining ion or constituent to the other. Thus two chemical elements or compounds are formed, having a tendency to combine or react; and when combination or reaction occurs on closing the circuit, the energy evolved appears as an electric current, which flows in a direction opposite to that of the charging current. This flow of current continues until the cell is restored to its original condition; when this occurs, the cell is said to be *discharged*.

A *Primary Cell* is one in which electrical energy is produced by the chemical action of one or two solutions on the plates of the cell. When the solutions or plates are exhausted, they are not restored to their original condition by the passage of an electric current in the same cell; but it is possible to regenerate or recover the solutions and metal by treating them electrolytically or chemically in other vessels.

An *Electrolyte* is a chemical compound capable of acting as an electrical conductor, and while so acting, undergoes chemical decomposition. This phenomenon is called *electrolysis*.

For example, when hydrochloric acid is decomposed by electrical energy, it is decomposed into the elementary gases hydrogen (H) and chlorine (Cl). The chemical formula for this action is,

$$2H\,Cl + \text{Electrical energy} = Cl_2 + H_2.$$

When sulphuric acid is electrolyzed, it is at first split up into hydrogen (H_2) and the radical sulphion (SO_4); the latter combines with the water of solution present and reforms sulphuric acid (H_2SO_4), oxygen being liberated. The chemical equations for the above primary and secondary reactions are:

$$2H_2O + 2H_2SO_4 + \text{Electrical energy} = 2H_2 + 2SO_4 + 2H_2O$$

$$2H_2 + 2SO_4 + 2H_2O = 2H_2 + 2H_2SO_4 + O_2$$

The modern theory of electrolysis is based upon the existence of free ions in every electrolyte. For example, a metallic salt dissolved in water is partially ionized; that is, a certain percentage is dissociated into the metal constituent and the other component part of the salt. These carry respectively positive and negative electrical charges, which are neutralized when the ions reach the negative and the positive plates of the battery. The various ions have definite velocities at which they travel or migrate through the electrolyte. The conductivity of electrolytes is entirely due to the presence of these ions, as the non-ionized portion does not conduct.

In 1802, soon after the invention of the primary cell by Volta, Gautherot demonstrated the fact that platinum wires, after being used to electrolyze saline solutions, were able to produce secondary currents. Volta, Ritter, Davy, and others noted similar effects, the phenomenon being what is commonly called *polarization.* In 1859, Planté undertook a series of experiments with the object of studying and magnifying this effect, and finally developed the Planté type of storage battery. Many of the most successful types of storage batteries of the present day are based upon Planté's invention.

Types of Storage Batteries:

Planté;
Faure;
Combination of Planté and Faure;
Non-lead.

PLANTE TYPES OF BATTERY

The Planté cell was originally made by placing two plates of metallic lead in a vessel containing dilute sulphuric acid. These plates were connected to an electric generator, and a current sent through the cell, which decomposed the electrolyte and oxidized the positive plate. The cell was then discharged; but the energy obtained was very small, since the action was confined to the immediate surface of the plates. By repeated charging and discharging, first in one direction and then in the other, the oxidation penetrated deeper and deeper into both plates, thus increasing the storage capacity of the cell.

The chief difficulty with the original Planté battery was the great length of time and consumption of energy required for *forming* the plates, which process, as just explained, consists in converting the surface of the plates into active materials, by repeated charging and discharging. Planté found that he could hasten this forming process by pickling the plates in dilute nitric acid, then washing them in a 10 per cent sulphuric acid solution, after which they were electrically formed. Other methods of facilitating the forming process, or increasing the active surface, are given later.

In 1881, Faure devised the method of *pasting* the lead oxide or active material directly upon the plates. This largely avoids the tedious forming process; but the plates thus produced are not so durable as the Planté elements, being more likely to disintegrate, because the paste is not an integral part of the plate.

General Principles of the Storage Battery. Any primary battery will act as a storage battery provided its chemical action is reversible. The ordinary gravity cell, for example, may be regenerated by sending a current through it in the direction opposite to that produced by it. The zinc sulphate and the metallic copper are thus reconverted into metallic zinc and sulphate of copper respectively, the chemical action being

$$ZnSO_4 + Cu + \text{Electricity} = Zn + CuSO_4,$$

which is exactly the reverse of the action in the primary cell. There are, however, practical difficulties in the continued recharging of a spent gravity cell, due to the ultimate mixture of the sulphate solutions so that the copper salt will reach the negative electrode, where it is deposited and sets up destructive local action. In some forms of primary cells, the chemical action liberates a gas that escapes, so that the action in these cases is obviously irreversible.

Chemical Action in Lead Storage Batteries. The exact nature of the chemical changes which occur in lead batteries, is not yet fully established. Planté believed the charging action to consist in the formation of peroxide of lead (PbO_2) on the positive plate, and metallic lead on the negative, which were converted into lead oxide (PbO) on both plates by the discharge. It was shown later by Gladstone and Tribe, and corroborated by subsequent investigations, that the formation of lead sulphate plays an important part.

This reaction may be represented as follows:

	Positive Plate		Electrolyte		Negative Plate
Charged Condition	PbO_2	+	$2H_2SO_4$	+	Pb
Discharged "	$PbSO_4$	+	$2H_2O$	+	$PbSO_4$
Charging Current			$\ggg\!\longrightarrow$		
Discharging Current			$\longleftarrow\!\lll$		

According to the above equations, the active material on both plates is converted into lead sulphate when the battery is discharged. The reasons for believing this to occur are: *first,* chemical analysis shows that lead sulphate exists in the discharged plate; *second,* the density of the electrolyte decreases during the discharge of the cell, corresponding to the consumption of sulphuric acid and the formation of water, as shown in the above reactions; *third,* on thermochemical grounds, the combination of lead and oxygen as lead oxide (PbO) does not evolve sufficient energy to account for the E. M. F. produced.

Storage Batteries of the Planté Type. It was noted that the first difficulty met with in the making of Planté plates was the inordinate length of time and cost of current necessary to form them; and it was also shown how Planté treated them with nitric acid to hasten this action. Other methods are used to facilitate the formation; these are tabulated as follows:

1. *Mechanical Action:* Laminated plates, made up of lead ribbons. The surface of the plate is grooved with some forming tool. Built up of lead wires, etc.
2. *Chemical:* Treating the plates in some pickling bath, to produce initial oxidation.
3. *Electrolytic:* Forming a plate of some compound of lead or an alloy, and either reducing the compound or eating the foreign matter away, leaving a porous lead plate.

Gould Storage Battery. This battery is made by the Gould Storage Battery Company, of New York, and the plates are produced by a combination of the first and third methods. The plates or blanks are placed in steel frames and given a reciprocating motion between two revolving shafts which carry grooving discs, giving the plates a surface as shown in Fig. 1. No lead is removed by this process; but the surface is ploughed up. It is then subjected to electro-chemical treatment to form the active material. The types manufactured range in size from a cell of three plates 3 inches by 3 inches, to one of 105 plates, each 15.5 inches by 31 inches; and in capacity from 5 ampere-hours in the smallest size to 17,000 ampere-hours in the largest.

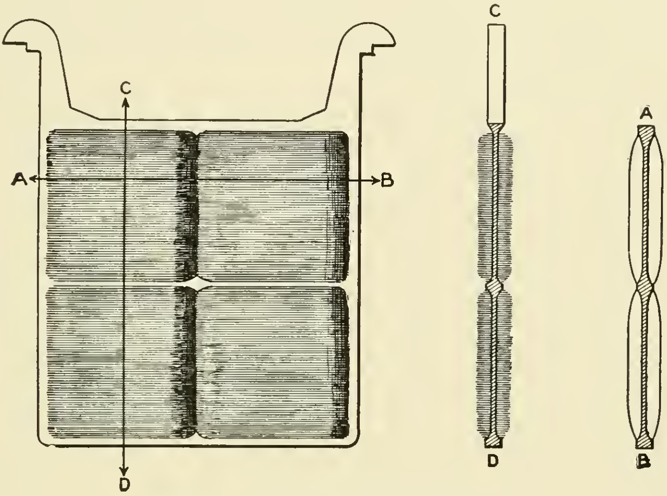


Fig. 1. Gould Storage-Battery Plate.

Bijur "High-Duty" Battery. Batteries of this type are manufactured by the General Storage Battery Company, of New York. They are made in standard sizes ranging from 6 ampere-hours to 12,688 ampere-hours, the smallest cell being made up of two plates, one positive and one negative, each 3 inches by 3 inches, suspended in a small glass jar. The largest type comprises 67 plates, each $15\frac{3}{4}$ inches by $31\frac{3}{4}$ inches, suspended in a lead-lined tank. Some of the standard sizes manufactured are shown in Table I.

Both positive and negative plates are of the Planté type, and are of the same general design, Fig. 2. Each plate consists of the grid or supporting frame, made up of pure lead containing a small percentage of refined antimony, producing a rigid inoxidizable supporting and conducting member for the active lead. In the openings of this rigid framework are welded gratings or *grills* of pure lead. Each grill consists of vertical strips supported by heavier horizontal

TABLE I

Data, Bijur High-Duty Battery

Type		BB	DDS	C	D		E		F		G		K		L	
Size of Plate (inches)		3x3	4⅛x8¼	3x5½	5½x5⅝		8⅛x8		10⅝x11		15¾x16		18¼x18⅝		15¾x31¾	
No. of Plates		2	2	7	5	11	5	15	7	19	11	57	21	71	19	67
Discharge Rate (in Amperes)	8 hrs.	¾	3	4.5	6	15	12	42	36	108	120	672	360	1,260	432	1,584
	5 "	1	4.2	6.5	8	21	17	59	50	151	168	942	504	1,760	605	2,218
	3 "	1½	6	9	12	30	24	84	72	216	240	1,344	720	2,520	864	3,168
	1 "	3	12	18	24	60	48	168	144	432	480	2,688	1,440	5,040	1,728	6,336
Normal Charge Rate		¾	3	4.5	6	15	12	42	36	108	120	672	360	1,260	432	1,584
Outside Dimensions of Glass Jar	Width	2⅜	3⅛	6¼	4¾	9⅛	5¼	13½	7⅜	....	....	....	....	....	....	....
	Length	3⅞	6⅛	6¼	7⅞	8⅛	9	9½	12¾	....	....	....	....	....	....	....
	Height	5⅜	12	10	10	10	12	12	16	....	....	....	....	....	....	....
Outside Dimensions of Lead-Lined Tank	Width	....	....	....	....	....	....	....	....	21¾	15⅛	54⅞	25	66½	23½	63¼
	Length	....	....	....	....	....	....	....	....	15	19¾	21½	24½	24½	22	22
	Height	....	....	....	....	....	....	....	....	17⅝	26	27½	31½	31½	48⅞	49⅞
Outside Dimensions of Glass Tanks	Width	....	....	....	....	....	....	....	....	20¼	....	....	....	....	....	....
	Length	....	....	....	....	....	....	....	....	13	....	....	....	....	....	....
	Height	....	....	....	....	....	....	....	....	18¼	....	....	....	....	....	....
Weight of Complete Cell, Incl. Acid and Containing Vessel (Pounds)		5⅝	19	25½	36	75	61	161	152	516 466	603	2,670	1,486	4,706	1,947	6,070

members which act as I-beams to stiffen it laterally, and which, with the vertical ribs, form the oxide cells. The active material is formed from the grill expanding as it grows in each of the minute oxide cells, thus locking itself in place.

The grills have no central web; and, being open structures, a through-and-through circulation of electrolyte is obtained. The grills are held on both sides by the alloy frame to which they are welded. A suitable space is provided between each end of the grill and grid to allow for vertical elongation, while the spacing of the strips accommodates the lateral expansion. The grills are therefore free to expand in every direction, thus avoiding the tendency to set up strains in the plates, which might cause them to buckle.

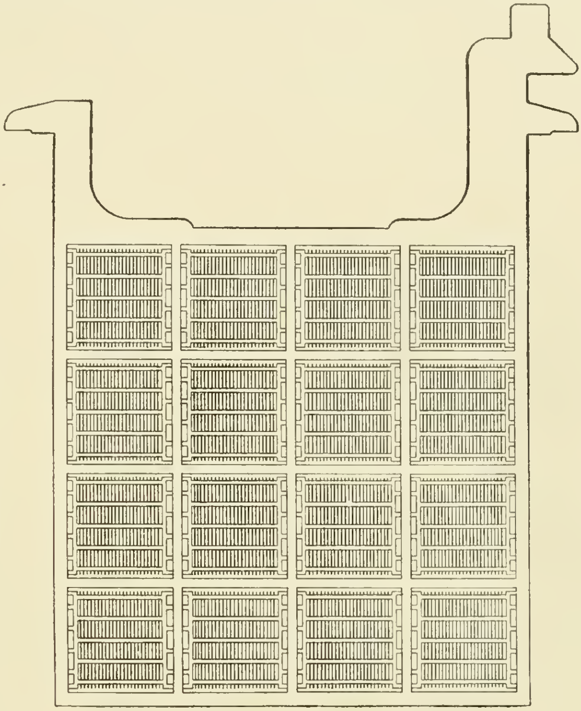


Fig. 2. Bijur High-Duty Battery Plate.

In welding the grills to the grid or frame, a heat process only is employed; no solder, flux, or foreign substance of any kind is used. Since the grill is an open structure, grown from which is a very thin layer of active material, and as this active material does not entirely close the small oxide cell, the gases evolved at high rates of charge have ready means of escape. This results in lower E. M. F.'s required for charging, and the acid diffusion thus obtained also maintains the E. M. F. when discharging at excessive rates.

With the closely adherent layers of active material in intimate contact with the metallic lead, and the absence of concentration of the electrolyte in the pores of the active mass, due to the diffusion, excessive sulphating does not occur.

The loss of negative capacity, due to shrinkage of the active material into a metallic mass, is avoided in this particular plate, by a special treatment which the plates undergo.

FAURE TYPES OF BATTERY

The difficulty with this type is the tendency to disintegrate or buckle. Various means intended to increase the permanency of adhesion of the active material have been suggested, of which the most important are as follows:

1. Plates are grooved, roughened, or *pocketed*.
2. Plates are entirely perforated, the holes being circular, or rectangular, and varying in cross-section; some have a uniform section through the grid (*A*, Fig. 3); others are contracted at the center (*B*); and again they have been expanded at the center of the grid (*C*).
3. The active materials may be enclosed in either a conducting or a non-conducting cage.
4. The plates may be made up entirely of active material.

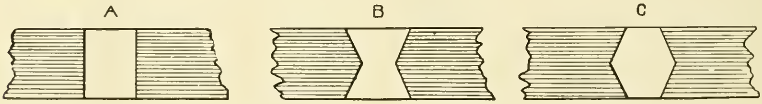


Fig. 3. Different Cross-Sections of Faure Plate Perforations.

Faure cells usually have a greater weight efficiency than those of the Planté type, because the proportion of active material may be made greater.

E. P. S. Battery. This is one of the most important of the Faure type, its name being the initials of the Electric Power Storage Company by which it is manufactured in England. It is sometimes called the "Faure-Sellon-Volckmar" cell, being based upon the work of these and several other inventors.

The plates consist of lead grids cast in an iron mould, and have the cross-section shown in Fig. 4. The later types have a thin perforated strip of lead running across each opening midway between the edges. The holes *A* in the grid are completely filled with a paste of red lead or minium (Pb_3O_4) and dilute sulphuric acid, for the positive;

while the paste for the negative consists of minium, or litharge (PbO), and dilute sulphuric acid, or a magnesium sulphate solution. These pastes are pressed into the grids and dried.

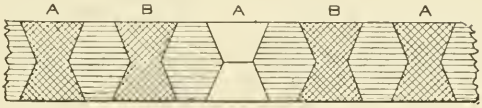


Fig. 4. Section of E. P. S. Battery Plate.

The plates are hardened in dilute sulphuric acid, after which they are ready for forming. A strong current of 48 hours' duration is required for the positive plate, and twenty-four hours is required for the formation of the negative plate. To prevent short-circuiting after the cells are set up, the plates have glass rod separators placed between them.

The E. P. S. batteries are made in many different sizes and forms, of which the L type is a good example, being used extensively in isolated plants. Data of this type are given in Table II.

TABLE II

Data, E. P. S. Accumulator, L Type

No. of Plates	Maximum Normal Charge or Discharge Rate	Capacity (Ampere-Hours)	Approximate External Dimensions			Weight Complete with Acid (Wooden Cell)
			Length	Width	Height	
7	13 amperes	130	5½ in.	13½ in. for wooden and 12 in. for glass cell	18 in. for wooden and 13½ in. for glass cell	74 lbs.
11	22 "	220	8 "			107 "
15	30 "	330	9½ "			143 "
23	46 '	500	14½ "			228 "
31	60 "	660	19 "			286 "

One of the smaller types of the E. P. S. battery is used extensively in England in electric vehicle work.

Exide Battery. This type is manufactured by the Electric Storage Battery Company, of Philadelphia, Pa., chiefly for electric vehicle duty. The plates are of the Faure type, and consist of lead-antimony grids (about 5 per cent antimony) pasted with oxides of lead.

The grid for the positive plate is of the cage type, consisting of thin vertical ribs the edges of which are flush with the faces of the plate and connected by small bars of a triangular cross-section; the bars on one face are staggered with respect to those on the other side. This finished form is then pasted up with red lead (Pb_3O_4), and formed in the usual way; the thickness of the finished plate is about $\frac{7}{32}$ inch. From this description it is evident that the plate is made up in accordance with method 3 described on page 8, the enclosing cage being of conducting material. The active material is in the form of rectangular pencils extending from the top of the plate to the bottom. The thin, flat ribs are on two sides of these pencils; and the triangular cross-pieces are imbedded in the other two sides which constitute the faces of the plates. The Exide cell is shown in Fig. 5.

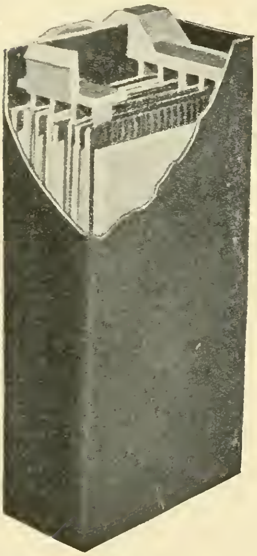
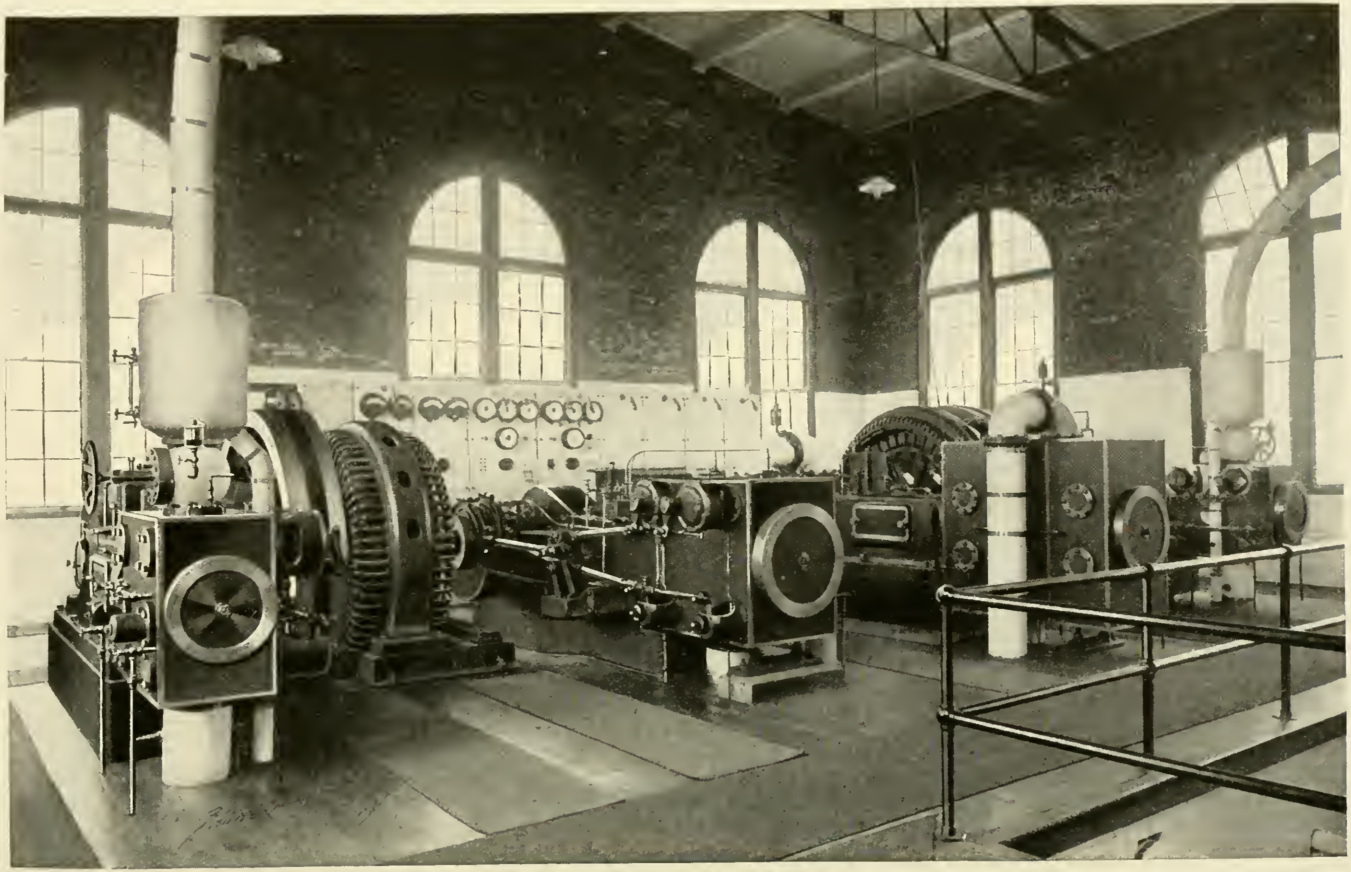


Fig. 5. Exide Battery.

The negative plate consists of a thin antimony-lead sheet, with a comparatively heavy frame of cast lead. The body of the sheet is perforated at regular points, about half an inch apart. These perforations, being made by a tool which does not remove the material, are not actual punchings; but are simply holes torn in the plate, leaving the surrounding material in ragged projections which curve back towards the sheet, forming, as it were, a series of hooks. These projections are formed on both sides of the plates.

The grid is then pasted with litharge (PbO) on both faces; it is held to the plate by the "hooks," as well as being riveted by passing through the holes which the projections surround. The thickness of this finished plate is about $\frac{3}{16}$ inch.

When assembled, the plates are placed in rubber jars of dimensions shown in Table III, and separated from one another by wooden partitions. In addition, a perforated rubber sheet is placed against the faces of the positive plates.



INSTALLATION OF ALTERNATING-CURRENT GENERATORS DIRECT CONNECTED TO BALL CORLISS ENGINE

Courtesy of Ball Engine Company

TABLE III
Data, Exide Cells*

TYPE	M. V.							P. V.			
NO. OF PLATES.......	7	9	11	13	15	17	19	5	7	9	11
DISCHARGE 4 HOURS. (Amperes)	21	28	35	42	49	56	63	12	18	24	30
SIZE OF PLATES—											
Length (inches) ...	5¾	same	same	same	same	same	same	$4\frac{13}{16}$	same	same	same
Height (inches) ...	8⅝	same	same	same	same	same	same	8⅝	same	same	same
OUTSIDE MEASURES OF RUBBER JARS—											
Width (inches)	$2\frac{7}{16}$	3¼	4¼	$4\frac{11}{16}$	$5\frac{3}{16}$	$6\frac{1}{4}$	$7\frac{3}{16}$	$1\frac{13}{16}$	$2\frac{9}{16}$	3¼	4¼
Length (inches)...	$6\frac{3}{16}$	same	same	same	same	same	same	$5\frac{5}{16}$	same	same	same
Height (inches)...	11½	same	same	same	same	same	same	11½	same	same	same
WEIGHT (lbs.)—											
Elements	15¾	20¾	25½	30¼	35	40	44¾	9¼	13¼	17¼	21½
Electrolyte	2½	3½	4½	6¼	7	8	8¾	1½	2¼	3	4½
Complete Cell......	19½	25½	31½	38½	$44\frac{1}{2}$	50	56	11½	17½	21½	27½

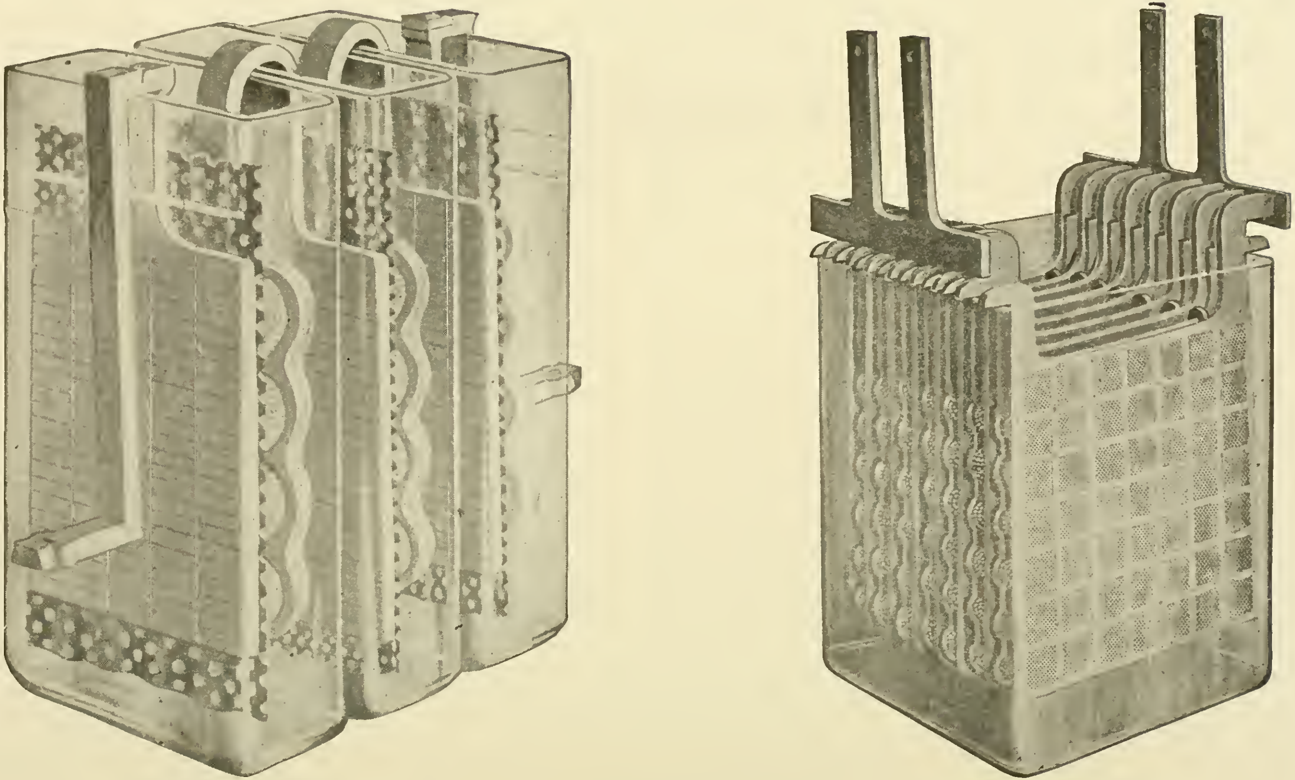
*NOTE.—For data on the "Express Type" of Exide cell, see literature of the Electric Storage Battery Company, Philadelphia, Pa.

The *brougham* or *hansom* battery of this type of cells consists of 44 cells of TV-9 size, having four positive and five negative plates. The weight of this outfit complete with tray is about 1,659 pounds; the capacity, 156 ampere-hours (4 hour, 39 ampere rate); the average voltage during discharge, about 1.98 volts per cell, or 87 volts for 44 in series; the total watt-hour output being therefore 13,572, or 8.18 per pound of battery complete including trays.

COMBINATIONS OF PLANTE AND FAURE TYPES

Chloride Battery. In the form which was manufactured until recently by the Electric Storage Battery Company and allied companies in England, France, and Germany, the Chloride Battery is a compromise between the Plante and Faure types, the positive being a Plante type and the negative of practically the Faure type.

The principal features in the manufacture of this battery are as follows: The first step is the production of finely divided lead, which is made by directing a blast of air against a stream of the molten metal, producing a spray of lead which, upon cooling, falls as a powder. The powder is dissolved in nitric acid (HNO_3) and precipitated as lead chloride ($PbCl_2$) on the addition of hydro-



B. T.—Couples in Glass Jars. Fig. 6. The Chloride Battery. Type F—15 Plates in Glass Jar.

chloric acid (HCl). This chloride, washed and dried, forms the basis of the material which afterwards becomes active in the negative plate. The lead chloride is mixed with zinc chloride and melted in crucibles, then cast into small pastiles or tablets about $\frac{3}{4}$ inch square and of the thickness of the negative plate, which, according to the size of the battery, varies from $\frac{1}{4}$ inch to $\frac{5}{16}$ inch. These tablets are then put in moulds and held in place by recesses, so that they clear each other by .2 inch and are at the same distance from the edges of the mould. Molten antimonious lead is then forced into the mould under about 75 pounds pressure, completely filling the space between the tablets. The result is a solid lead grid, holding small squares of active material. The lead chloride is then reduced by stacking the plates in a tank containing a dilute solution of zinc chloride, slabs of zinc being alternated with them. This assemblage of plates constitutes a short-circuited cell, the lead chloride being reduced to metallic lead. The plates are then thoroughly washed to remove all traces of zinc chloride.

In the new form of negative plate which has replaced the chloride type just discussed, the negative consists of a pocketed grid, the openings being filled with a litharge paste; it is then covered with perforated lead sheets, which are cast integral with the grid.

The positive plate is a firm grid, composed of lead, alloyed with about 5 per cent of antimony, about $\frac{7}{16}$ inch thick, with circular holes $\frac{25}{32}$ inch in diameter, staggered so that the nearest points are .2 inch apart. Corrugated lead ribbons $\frac{7}{16}$ inch wide are then rolled up into close spirals $\frac{25}{32}$ inch in diameter, which are forced into the circular holes of the plate. These spirals are electrochemically formed into active material. The process requires about thirty hours; at the same time, the spirals expand so that they tend to fit still more closely in the grids. This form of positive is that known as the *Manchester Plate.*

Recent types of "Chloride accumulator" are shown in Fig. 6. In setting up the cells, the plates are separated from one another by thin wood partitions having vertical grooves to facilitate the rising of the gases. These separators are stiffened by split wooden pins slipped over them. Sometimes glass tubes are used as separators.

Table IV gives data of the various types and sizes of cells. To save space, only the smallest and largest sizes of each type are given;

TABLE IV
Data, Chloride Battery

TYPES		B	C		BT	CT	PT	D		E		F		G		R*		H	
Size of Plate, inches...		3x3	4⅜x4		3x4	5x5	8¾x5	6x6		7¾x7¾		11x10½		15½x15⅛		18⅝x18⅝		15½x31	
NO. OF PLATES....		3	3	7	2	2	2	3	13	5	15	9	27	11	75	25	75	21	75
DISCHARGE IN AMPERES	For 8 hrs.	⅝	1¼	3¾	¾	1½	3	2½	15	10	35	40	130	100	740	360	1,110	400	1,480
	5	⅞	1¾	5¼	1	2	4¼	3½	21	14	49	56	182	140	1,036	510	1,550	560	2,072
	3	1¼	2½	7½	1½	3	6	5	30	20	70	80	260	200	1,480	720	2,220	800	2,960
	1	....	....	....	....	....	....	10	60	40	140	160	520	400	2,960	1,440	4,440	1,600	5,920
NORMAL CHARGE RATE..........		⅝	1¼	3¾	¾	1½	3	2½	15	10	35	40	130	100	740	360	1,110	400	1,480
OUTSIDE DIM. OF GLASS JARS (inches)	Width	2½	3½	5¼	1¾	2¼	2½	3¼	11	5½	11	9	No glass jars for these large sizes.						
	Length	4	5¼	5¼	3¾	6¼	6	7⅞	8¼	9⅛	9⅛	12⅝							
	Height	6½	7¼	7¼	6¾	8	12	9½	9½	11⅜	11⅜	17							
OUTSIDE DIM. OF LEAD-LINED WOODEN TANKS	Width	....	....	....	....	....	....	....	....	....	....	13⅜	28⅜	15⅛	69⅞	24¾	24¾	25⅛	69⅞
	Length	....	....	....	....	....	....	....	....	....	....	15	15	19¾	21½	28⅜	69⅞	21½	21½
	Height	....	....	....	....	....	....	....	....	....	....	20¼	20¼	26	27⅞	31½	32½	48¾	49¾
WEIGHT OF CELL COMPLETE (lbs.)		5½	10½	19	3½	7½	13½	19½	64	48¾	112	175	....	....	....	....	....	....	...
DITTO. LEAD-LINED TANKS...		....	....	....	....	....	....	....	....	....	....	250	615	561	3,260	1,641	4,616	1,885	5,986

* This size of cell is listed by its manufacturers on the 6, 2 and 1 hour rates; but for purposes of comparison it is brought to the same basis as the other sizes.

but in all cases intermediate sizes are made with every odd number of plates. The capacities, weights, etc., are of course nearly proportional to the number of plates.

The smaller sizes are provided with either rubber or glass jars, and the larger ones, from F up, with lead-lined tanks.

Tudor Cell. This type is very extensively used in Europe, and to some extent in this country, although it is no longer manufactured here. The American patent rights are controlled by the Electric Storage Battery Company.

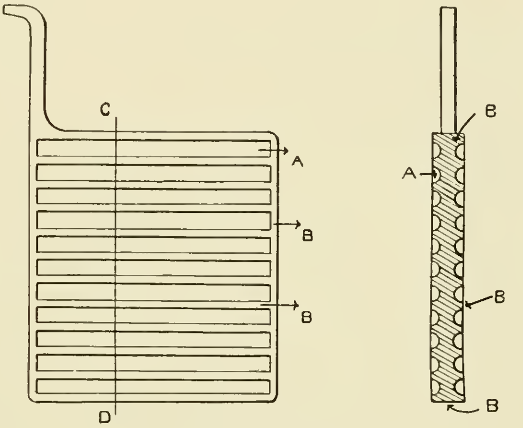


Fig. 7. The Tudor Battery Plate.

The plates consist of rolled, grooved sheets as shown in Fig. 7, *A* being the hollows or grooves into which the paste is set, and *B* the lead frame. The thickness of the plate between opposite grooves is about .12 inch for the positive and about .06 inch for the negative. The width of grooves on the positive plate is also about .12 inch, while on the negative it is about .08 inch. The grooves are first coated with a thin layer of peroxide of lead (PbO_2) by electrolysis, and then packed with the oxides as required; the plates are then rolled to *fix* the paste. This treatment of the grid with an electrolytic bath before applying the active material, is covered by United States patent No. 413,112.

TABLE V

Tudor Cells

Type	Available Capacity	Maximum Current (in amperes)		Dimensions of Cells (in centimeters)			Total Weight
	Amp.-Hours	Charge	Discharge	Length	Width	Height	Kgms.
I	26	6	8	12	21	35	10
V	91	21	28	30	21	35	30
X	270	54	72	42	42	55	110
XIV	630	126	168	74	42	55	230

In addition to the sizes given in this table, all the intermediate sizes are made.

Lithanode. Mr. Desmond Fitzgerald has made storage batteries with a positive plate consisting entirely of active materials made up of litharge (PbO) mixed with ammonium sulphate $(NH_4)_2SO_4$ which he pressed into the required shapes. This plate is converted into peroxide by chemical treatment. The negative consists of the ordinary lead plate. While this cell has an exceedingly high weight efficiency, it is not of much commercial importance, though used considerably in laboratory work.

It is the tendency in Europe to make the positive plate of the Planté form, and the negative of the Faure or pasted type. The reason for this is that the Planté form is hard to make; and as the activity is small on the negative, the pasted plate is good enough.

The practice in lead batteries is to make the negative plate of greater capacity than the positive, as the charging and discharging of a cell in service tends to produce or form more active material on the positive plate, whereas the negative plate is made to decrease, so that allowance for this is made as above stated. A still further allowance is made to cover this action, by always having one more negative than positive plate in a cell.

Storage Batteries Containing Metals Other than Lead. It has already been stated that almost any primary cell will act more or less as a secondary cell; as, for example, the common gravity battery. A great many have been devised in which the lead in one or both of the plates has been replaced by some other metal. For example, Reynier made the negative plate of zinc instead of lead, this zinc in discharging being converted into zinc sulphate, which dissolved in the electrolyte. The substitution of zinc for lead secures an increase in initial E. M. F. from 2.2 to 2.5 volts, and also allows of a considerable reduction in weight, since for the storage of a given amount of energy the weight of the zinc required is much less than that of the equivalent lead. A difficulty with this type of cell is the formation of *trees* of zinc on the negative plate during the charging process, which are likely to fall off or extend across to the positive plate, thus short-circuiting the cell.

Another difficulty is the difference in density of the solution between the top and bottom of the plates, the tendency being to exhaust the zinc sulphate from the upper portion of the liquid during charging. In order to avoid this trouble, the plates have been arranged horizontally, so that the density would be uniform for each plate; but the difficulty then arises that the gases which form to a certain extent in almost all batteries collect between the plates and interfere with the chemical action and the passage of the current.

A similar type of cell has been manufactured by the Union Electric Company of New York, in which the negative plates consist of thin sheet copper covered with an amalgam of zinc, and the positive plates are made up of laminæ of lead held together by leaden rivets and perforated with numerous small holes, these positives being formed by the Planté process.

Waddell=Entz Accumulator. The copper alkali-zinc primary battery of Lalande, Chaperon and Edison being reversible in action, can be used as a storage battery. Waddell and Entz have constructed accumulators on this principle. When discharged, the positive plate consists of porous copper; on charging, the electrolyte is decomposed, metallic zinc being deposited on the negative plate; the porous copper of the positive plate is oxidized, and the liquid becomes converted into a solution of caustic potash (potassium hydrate).

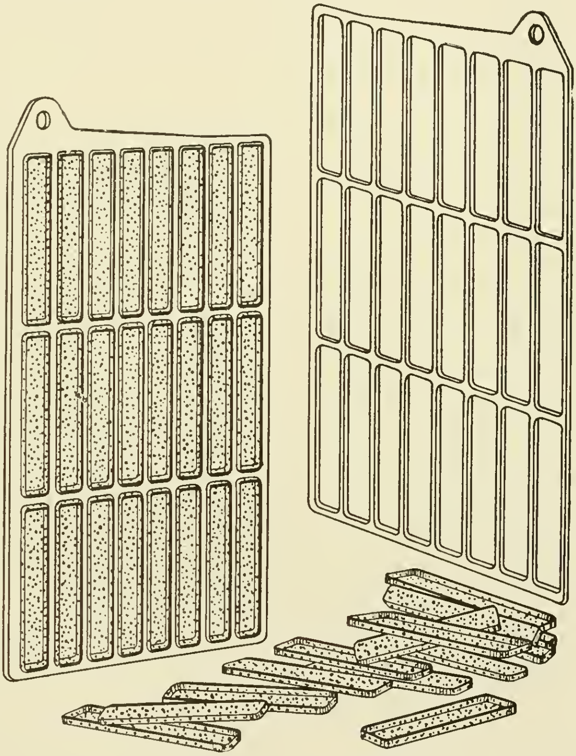


Fig. 8. Plates and Receptacles of the Edison Cell.

This storage battery was formerly used with considerable success for traction purposes; but its E. M. F. is so low, being only about .7 volt, that it would require 170–180 cells for the ordinary 110-volt electric-lighting circuit, allowing for loss of potential in the battery and conductors. This number is three times as great as is required with the lead battery. This is a serious objection to this or any other low-voltage cell.

Edison Storage Battery. The standard cells of this type are 13 inches high, 5.1 inches wide, and vary in length according to their rating, the various capacities being obtained by simply increasing the number of plates. The positive and negative plates are alike in appearance, and consist of rectangular grids, of nickel-plated iron, each about 9½ by 5 inches by .025 inch, punched with three rows of rectangular holes, eight holes to the row (Fig. 8), each hole being filled by a shallow perforated box of nickel-plated steel, the perforations being very fine, about 2,500 per square inch.

The difference between the positive and negative plates is entirely in the contents of the perforated receptacles; those for the positive plate containing a mixture of oxide of nickel and pulverized carbon, the latter being employed to increase the conductivity of the active material. The compartments of the negative plates contain a finely divided oxide of iron and pulverized carbon. When filled, these receptacles are secured to the grid by placing them in the openings of the same, and subjecting the assembled plate to a pressure of about 100 tons, which expands the pockets and fixes them firmly in the grid. A set of assembled plates as employed in a complete battery, is shown in Fig. 9.

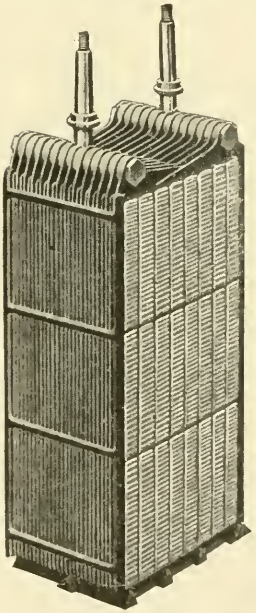


Fig. 9.
Complete Edison Cell.

The electrolyte consists of a 20 per cent solution of caustic potash, which, however, undergoes no chemical change during the process of charge or discharge, acting simply as a conveyor of oxygen between the plates. The charging current, entering at the positive plates, oxidizes the nickel compound to the peroxide state, and reduces the iron compound in the negative plates to a spongy iron mass. The containing vessel consists of nickel-plated steel; and the plates are strong individually and close together, being separated by thin strips of vulcanized rubber, thus forming a compact mass. The terminals of the plate pass through the cover of the cell, from which they are insulated by vulcanized rubber bushings.

The electrical features of the Edison cell are as follows:

Average voltage of charge at normal rate, 1.68.
Average voltage of discharge at normal rate, 1.24.

A set of charge and discharge curves of a 180-ampere-hour cell is shown in Fig. 10. This battery is rated at 30 amperes for a period of six hours. The various cells have a weight efficiency of 11.5 to 13.2 watt-hours per pound, depending upon the size. The watt efficiency under normal working conditions is about 60 per cent. The charging and discharging rates are alike, and cover wide ranges. A cell may be charged at a high rate in one hour, without apparent detriment except lowering the efficiency slightly. It is not appreciably influenced by temperature changes, and may be fully discharged to the zero-point of E. M. F., or even charged in the reverse direction, and then recharged to normal conditions, without suffering loss in storage capacity or other injury. The best results are obtained when twice as many positive as negative plates are employed; and the standard cells are made up on this basis. This type is intended especially for electric automobile service, by virtue of its high weight efficiency and its ability to endure rough mechanical as well as electrical treatment. The same qualities would also adapt it to portable electric-lighting purposes.

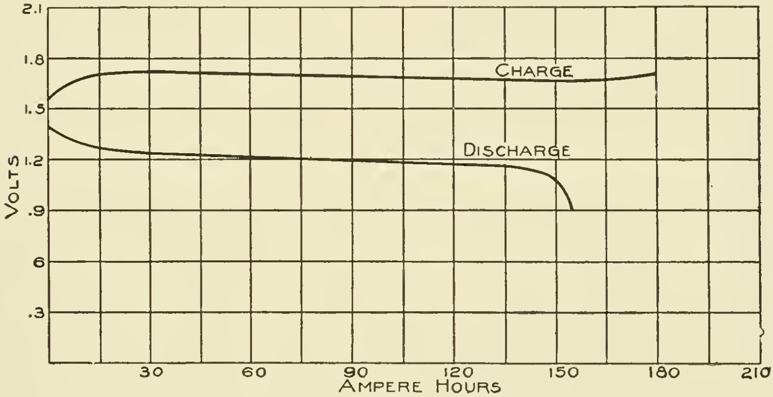


Fig. 10. Charge and Discharge Curves of Edison Cell.

MANAGEMENT OF STORAGE BATTERIES

In describing the handling of storage batteries, the various types of lead cells will be considered, as they constitute a very large majority of the cells in commercial use.

Battery Room. In the installation of a battery, the first point to be considered is its location. The room for this purpose should be dry, well ventilated, and of a moderate temperature; otherwise, not only will the evaporation of the electrolyte be excessive, but if the temperature be very high, the plates themselves will be affected and their life shortened. The floor, walls, and ceiling must be of some acid-proof material, brick or tile being preferable, and the floor so made as to drain readily, an outlet being provided to the drainage system. If the room should be an old one, and have a wooden floor, the floor should be coated with asphaltum paint, and lead trays placed below the batteries; any woodwork or ironwork in the room should be likewise treated.

The room should be sealed from the rest of the building, and located near the generating machinery and distribution switchboard, so that the copper cables may be low in cost. The windows in the battery room should be of either ground or painted glass, so that no direct rays of the sun may strike the cells, as the heat might crack the cells (glass) or increase the activity of the acid, which is not desirable.

In case the battery installation is in a cold climate, some device for keeping the electrolyte at a moderate temperature must be used.

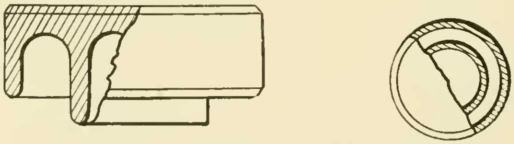


Fig. 11. Glass Insulator for Battery Support.

Setting Up the Cells. The battery is usually placed on the floor, or upon strong wooden shelves; Fig. 11 shows a form (made of glass or porcelain) adapted to cells of medium size. Iron stands are sometimes used for large and heavy cells, but they must be protected from acid fumes and drip by several coats of an acid-proof paint. Wooden stands should be varnished, painted, or soaked in paraffin for the same reason. It is important to have every cell accessible for inspection, cleaning, and removal, it being desirable to reach both sides of the cell. There should also be sufficient headroom between shelves so that the elements may be lifted out.

It is highly important that the cells be thoroughly insulated from one another, to avoid leakage of current. This is accomplished by standing each cell on four insulators of porcelain or glass of the design shown in Fig. 11. Glass is now almost universally employed because porcelain is frequently found to deteriorate gradually as a result of the action of the acid fumes.

Lead-lined tanks for 500-volt installations are usually set as follows: The floor is covered with a layer of glazed tile or brick; on this are placed two wooden stringers about 3 by 4 inches, carefully painted with asphaltum varnish or some acid-proof paint. Under each tank are set four or more insulators held in place by wooden pegs which are kept in position by pouring melted sulphur around them. Sometimes the insulators have short, threaded projections on the top, which are screwed into the bottoms of the tanks. On top of these are placed the battery tray and battery as indicated in Fig. 11.

In the case of 125-volt installations, the insulators are sometimes set directly on the tile flooring, which has been leveled by running molten sulphur under the tiling.

Oil insulators were at first used; but oil collects and holds dust, and, as dust is likely to cause leakage, they are no longer employed. For very large lead tank outfits, a double system of the supporting construction shown in Fig. 12 is used, but with individual stringers for each cell.

Glass cells are often set on wooden trays, which are filled with sand to distribute the strains and absorb the drip. Sawdust was formerly also used; but it becomes carbonized by the acid drip, and, as this is likely to cause leakage, it has been abandoned.

In connecting the cells, which are usually put in series, great care should be taken to join the positive terminal of one cell to the negative of the next, and so on. The color of the plate is the best indication of its polarity, the positive plate being a light brown when discharged and a chocolate color when charged, while the negative varies from a light to a dark slate color.

It may be noted at this point, that the nomenclature concerning storage batteries is different from that of primary cells. The positive

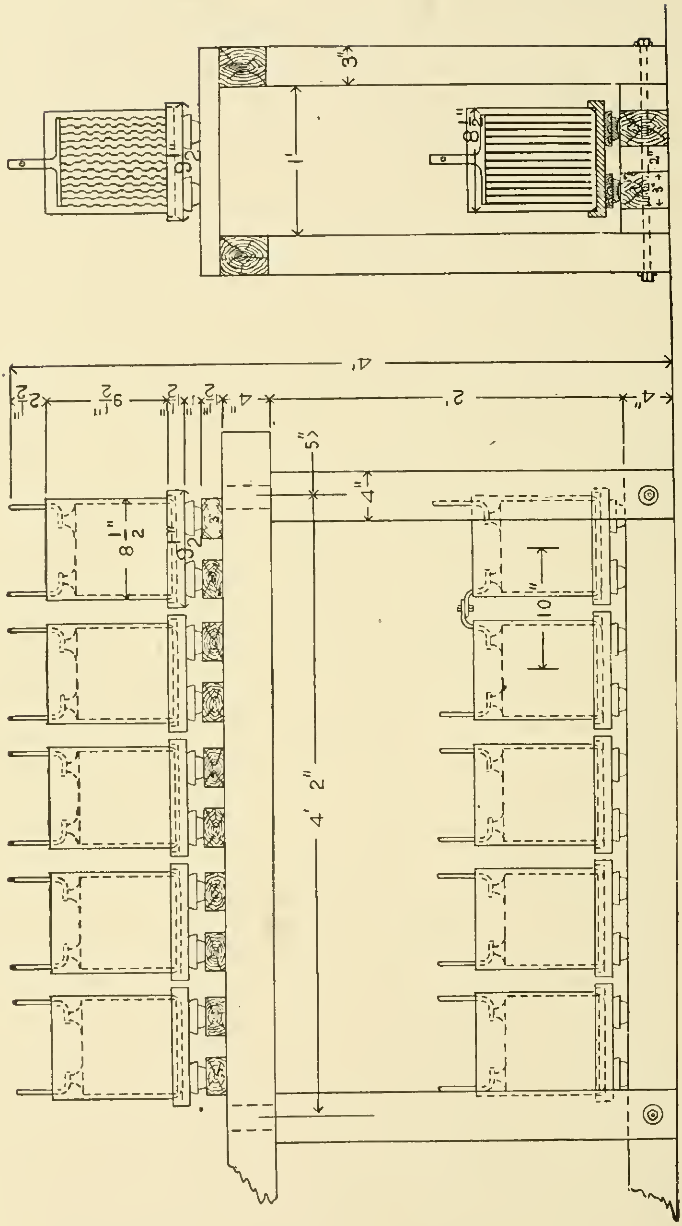


Fig. 12. Shelf Construction for Battery Support.

plate in the former is the peroxide plate (brown), and is that one from which the current flows out in discharging; whereas that would be the negative plate (positive pole) of a primary cell, viz, Cu. or C.

The positive pole or terminal in a storage battery is an extension of the positive plate, and is connected to the positive terminal of the dynamo in charging; consequently there is much less cause for confusion of terms than there is in the primary cell.

It is well to test the polarity of each cell and of the circuit, before making connections. This may be done with any form of pole-tester, or by the positive expedient of dipping the two terminals in dilute sulphuric acid, the one from which the most bubbles arise being negative. The connections should be scraped clean and screwed up very tight, then coated with acid-proof paint to avoid corrosion. The most satisfactory way to connect up a cell is to weld or *burn* the positive terminal to the negative terminal of the next cell, though soldered connections are good.

This soldering is done as follows: Two strips of lead and the terminals to be connected are very carefully cleansed; the lead strips are then clamped to the terminals, a mould placed around the joints, and molten lead poured into it.

The Electrolyte. Practice varies considerably as to the strength of solution to use. Chemically pure sulphuric acid is poured into water until its density becomes about 1.2, and then the mixture is allowed to cool before pouring it into the cells. The electrolyte *should completely cover* the plates. Cells for vehicle work use an electrolyte with density as high as 1.3. It is important to use perfectly pure acid and water, as impurities will cause local actions and ultimately destroy the plates.

It is well to remember that *water should never be poured into sulphuric acid,* as it is likely to cause the liquid to be thrown out violently.

The advantage of a strong solution is its lower resistance; but it is likely to produce the very objectionable effect of *sulphating.*

The density of the electrolyte falls immediately after filling a cell, since some of the acid is taken up by the plates; but it rises again in charging—for example, from 1.17 to 1.2. It is convenient to keep a hydrometer in several cells to observe the density of the electrolyte, not only at the beginning, but as a permanent indicator of the amount of charge and general working conditions.

The hydrometer is an instrument for determining the specific gravity of a liquid, and consists of a weighted bulb and an upright glass rod, bearing a scale, the unit point being fixed by the distance to which it sinks in pure water at 4°C. Readings above this point are for solutions of lower specific gravity than water, and those below it are for solutions of a higher specific gravity. For storage battery work, the specific gravity of the electrolyte is always between 1.1 and 1.3; hence we require only a certain portion of the scale as represented in Fig. 13.

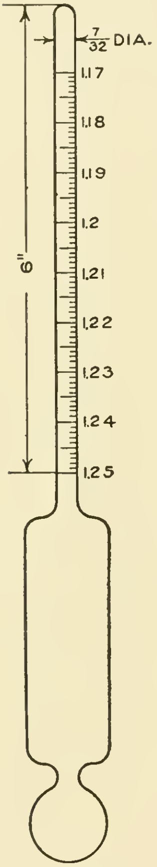


Fig. 13.
Hydrometer.

Charging. The charging should begin immediately after a new cell is filled with the electrolyte; otherwise the plates are likely to become sulphated. The first charge differs from subsequent regular charges in that it should be at a rate (lower than normal) that will not cause the temperature of the cell to reach 100°F.; but in all other respects it is the same.

Indications of Amount of Charge in a Storage Battery. There are various methods of ascertaining the amount of charge in a storage battery. The following are the indications that will serve the purpose:

1. The E. M. F. rises from 2.1 volts, at the beginning of the charging of a lead cell, after it has been discharged, to approximately 2.5 volts when fully charged, although this value may be made a trifle higher or lower, depending upon the rate of charge and temperature of cell. The rise is quite gradual, but more rapid near the beginning and end of the charge, as indicated in Fig. 14. When the cell is fully charged, the E. M. F. becomes constant, and the curve approaches a horizontal line as shown. The charging should then be stopped, as any more energy passed through the cell is simply wasted in producing gases. The external voltage is higher in charging than in discharging, because of the internal resistance of the cell and resulting IR drop, which must be overcome in charging.

The measurements of voltage should always be made when the current is flowing either in charging or discharging.

The E. M. F. on open circuit has little practical significance, since a cell, no matter how low it may have been discharged, will show about 2.1 volts after standing on open circuit a short while.

2. *If a record is kept* of the exact number of ampere-hours of charge and discharge, the actual amount of energy in the battery at any time is known, due allowance being made for leakage and other losses. For this purpose any integrating instrument, such as the Thompson recording wattmeter, may be used.

3. *The density of the electrolyte* gradually rises during the charging operation (Fig. 14), the density when charged being about .025 higher than when discharged. There is a lag in the change of the density of the electrolyte, the acid not being absorbed or given off at once by the plates; hence a little time should be allowed before taking any hydrometer reading as final. It is also advisable

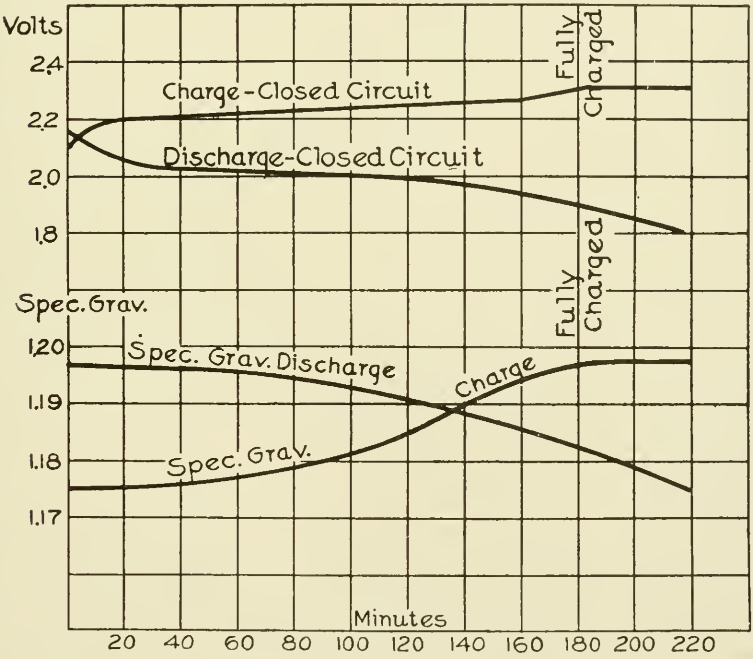


Fig. 14. Curves Showing Variations in Specific Gravity and Voltage in a Storage Battery during Charge.

to agitate the electrolyte to insure complete diffusion, as the electrolyte at the bottom of the cell is otherwise denser than at the top.

4. *Bubbles of gas are given off* freely when the battery is fully charged, since the material of the plates is then no longer able to take up the oxygen and hydrogen which tend to be set free by the electrolysis; these bubbles give the electrolyte the appearance of boiling, and often they are so fine that the liquid looks almost milky white, particularly in a cell which has not been very long in use.

5. *The color of the positive plates* varies from a light brown on active parts to a chocolate color when fully charged, and to nearly black when overcharged. The negatives vary from pale to dark slate color, but they always differ in color from the positives. This indication of the amount of charge is acquired by experience, but is quite definite after one becomes familiar with a particular battery.

6. *Cadmium Test.* The apparatus for making this test consists of a small piece of cadmium, say $\frac{5}{8}$ by $\frac{5}{8}$ by $\frac{1}{32}$ inch, contained in a perforated hard rubber casing (shown in Fig. 15), the rubber covering being employed to prevent short-circuiting of the cell during the test (see Fig. 15). A rubber sleeve contains the conducting wire, wax being used to protect the soldered joint of copper and cadmium. Cadmium is used because it will give reliable readings of the E. M. F. of the positive and the negative plates, with respect to itself. In this way a relative condition of the battery and also of each plate can be determined.

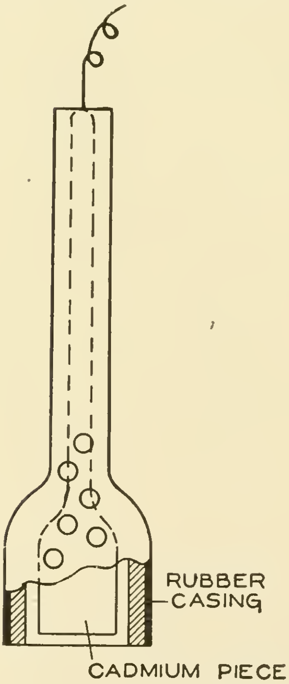
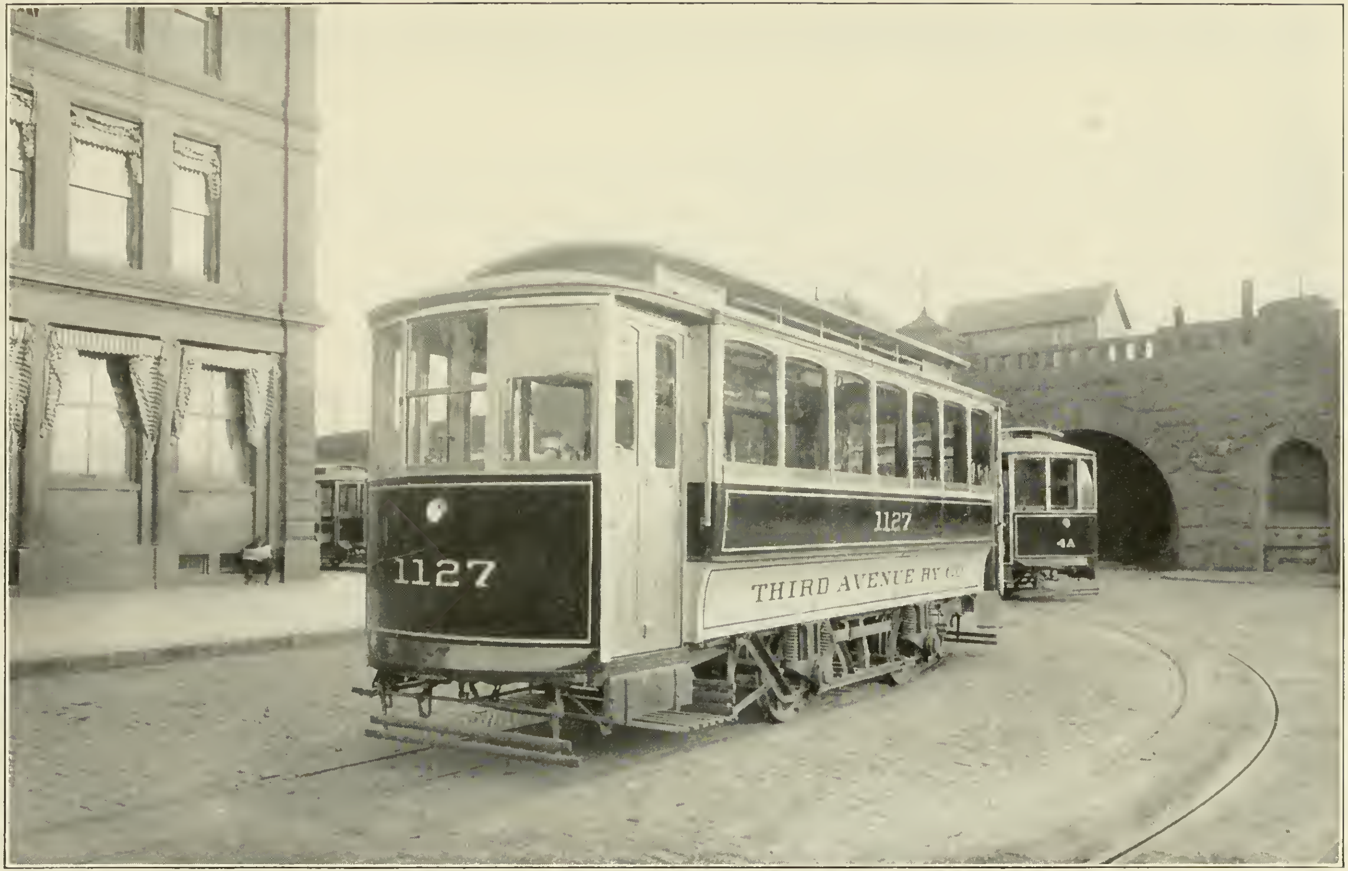


Fig. 15. Cadmium Test-Piece.

With normal conditions of cell, when fully charged and in open circuit, the difference of potential between the positive and the cadmium piece immersed in the liquid is 2.5 volts or nearly so, and between the cadmium and the negative plates is zero or nearly so. In fact it is sufficient if the sum of the readings is about 2.5 volts.

To avoid false conclusions in making a cadmium test, hydrom-



STORAGE BATTERY CAR OF LIGHT CONSTRUCTION AND EQUIPPED WITH BALL-BEARINGS
These cars may be operated over a maximum distance of 137 miles on one charge

eter, temperature, and charge data should be noted. The cadmium test is usually made by inserting the tester at the center of the cell to get a uniform current distribution. This test gives readings the sum of which is less than 2.50 volts, when hydrometer tests, temperature, and charge data show that the cell is not fully charged. If the hydrometer, temperature, and other data show the charge to be completed, and the cadmium test gives .1 volt or more below 2.5 volts, one or more plates are defective and may be found by individual cadmium readings. For example, suppose we have a cell in which all the other conditions tend to show full charge, but the potential difference is low. A cadmium test is made; and the set of plates which shows the falling off from normal reading is the defective one, and should be examined for some of the troubles that will be discussed later.

In some cases the cadmium reading with respect to both positive and negative plates may approach zero; this is caused by a short circuit in the cell, which should be found and removed immediately.

In practice it is advisable to have the cadmium wet before the test is made, as the readings increase when cadmium is first placed in the electrolyte. The simplest way to accomplish this is to keep the cadmium tester in a beaker of distilled water when not in use. All foreign matter should be carefully removed from the cadmium, as it might affect the results. If gas bubbles collect on the cadmium, they should be taken off, as they tend to lower the readings.

The proper rate of charge depends upon the size and type of cell, and is usually specified by the manufacturer in each case, since it is merely an empirical fact, being determined by the construction of the plates.

The current for charging is ordinarily obtained from a direct-current dynamo, but any other direct-current source may be employed. The potential required for charging must exceed that of the battery, which, during the operation, acts as a counter-E. M. F., the expression being $I = \frac{P-e}{R}$, in which I is the current, P the potential applied to battery terminals, e the counter-E. M. F., and R the internal resistance of the cell. Usually P is 5 to 10 per cent greater than e, in order to cause the necessary charging current to flow through the resistance R of the cell.

In practice, P is regulated until the required charging current I is obtained.

The above equation, put into form of $R = \frac{P-e}{I}$, enables the internal resistance R to be calculated; but, as this varies considerably with the temperature and with different states of charge, its exact value is not often considered.

Another form of the above equation, $e = P - IR$, shows that the true, or counter-, E. M. F. of the battery is less than the charging voltage by an amount equal to the product of the charging current and the internal resistance. Conversely, in discharging, the total E. M. F. of cell is greater than the difference of potential between its terminals, by the same amount. Hence it is necessary to know I and R, in order to find the real E. M. F. of cell. This applies to each individual cell, as well as to the entire battery, and is important in determining the amount of charge or working condition of a particular cell.

If the charging voltage P be kept constant, it is evident from the above equations that the current I will gradually decrease, since the C. E. M. F. or e of the cell steadily rises as shown in Fig. 16. This effect is counteracted somewhat by the fact that the internal resistance R also diminishes, owing to the density of the electrolyte increasing. This gradual reduction in the strength of the charging current is considered desirable by some authorities, since it enables the cell to take a greater charge than if the current were maintained

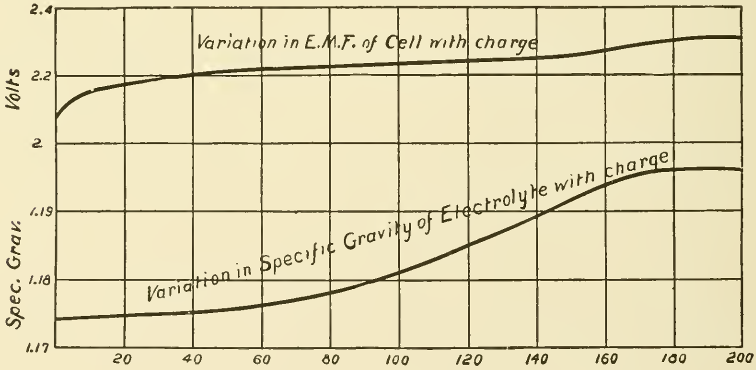


Fig. 16. Curve Showing Increase of E. M. F. in a Charging Cell.

at full strength. On the other hand, this diminishing charge makes it difficult to keep account of the exact number of ampere-hours supplied to the cell; hence, in ordinary commercial work, it is considered simpler to charge with a constant current, and if it is desired to keep the cell temperature down, the current is decreased near the end of the charge. The charging operation may be continued until the battery is fully charged as shown by the indications already stated. Since most types of cells are not injured by a slight overcharging at a moderate rate, it may even be carried a little beyond the charged point, as it tends to remove sulphating. A considerable overcharge should be avoided, as it causes excessive formation of gas bubbles in the active materials and is likely to heat the cell and even to cause disintegration and buckling of the plates.

Discharging. A storage battery is in most cases discharged within a few hours after being charged, as, for example, in electric lighting, when the engine and dynamo are run during the day for charging the battery which supplies current to the lamps during the night. But a portable battery for feeding lamps or a vehicle battery might be required to retain its charge for several days. The loss of charge in any battery standing on open circuit is about 25 per cent in one week, but for one day or less it is quite small.

Even when the discharge occurs immediately, the average voltage and the ampere-hours obtained are less than for the charge, as explained under "Efficiency." The loss referred to is additional, depending upon the time.

The operation of discharging is naturally the converse of charging, the changes which have been described as occurring in the latter take place also in the former, but in the reverse order. The normal rate of discharging is usually equal to that of charging, but may be somewhat greater. In some cases it is necessary to discharge at higher rates; but, by so doing, a percentage of the capacity in ampere-hours is sacrificed.

For example, a cell whose normal or eight-hour discharge rate is 100 amperes, can easily be discharged at 400 amperes for one hour, but only 50 per cent of the cell's capacity in ampere-hours is obtained at the latter rate. Under these latter conditions, there is not a large loss of energy, as is shown by the fact that to recharge a cell thus discharged requires only about 50 per cent of the normal charge.

TABLE VI

Percentage of Capacity Variation at Different Discharge Rates

RATE IN HOURS	PERCENTAGE OF CAPACITY AT 8-HOUR RATE		
	Planté	Planté (+) Faure (−)	Faure
8	100	100	100
7	99	97	96
6	96½	93½	92
5	93	89	86
4	88	83	80
3	80	75	72
2	70	65	61
1	55	50	40

An excessive discharge rate is injurious to most types of storage-battery plates, since it tends to disintegrate the plates, and abnormally heats the electrolyte, which hastens the disintegration. It is therefore advisable to protect the battery with fuses or a circuit-breaker.

A storage battery *should never be discharged completely*, as it is very likely to become sulphated or otherwise injured; and moreover the voltage falls so rapidly towards the end of discharge that the current would be of no practical value. The limit of discharge is usually considered to be the point at which the voltage drops to 1.75, though when cells are used at the one-hour rate the limit of discharge is 1.6 volts.

A battery should never be allowed to stand in a discharged condition, but should be recharged immediately.

The charge usually left in a storage battery is from 10 to 30 per cent of the total capacity, depending on the rate of discharge; but this involves no considerable loss of energy or efficiency, since it remains in the battery each time, and the charging begins at that point.

Efficiency of Storage Batteries. The efficiency of any apparatus is the ratio between output and input. In a storage battery it is the ratio of the amount of discharge to what is required to bring the battery back to its original condition after a discharge.

The *ampere efficiency*—or, more properly, the *ampere-hour efficiency*—which is the ratio of current in ampere-hours drawn from the battery to current in ampere-hours put into the battery, is quite different from the *watt-hour efficiency*. The latter is the *real efficiency* since it considers the energy, and includes the voltage as well as the ampere-hours. The former may be used either through ignorance or intention to give a false idea, since the ampere efficiency is often 15 per cent higher than the watt efficiency.

Another difficulty is the fact that it is possible to obtain an apparent efficiency of over 100 per cent from a storage battery. Since a certain amount (about 25 per cent) of charge is always left in the cell, it is possible to draw more ampere-hours than were put in during the last charge, by simply discharging the cell more than usual.

This matter has been investigated by Ayrton, who says:

> "If an E. P. S. accumulator be over and over again carried around the cycle of being charged up to 2.4 volts, and discharged down to 1.8 per cell, the charging and discharging currents being the maximum allowed by the makers—namely, .026 ampere per square inch of surface in charging, and .029 ampere per square inch in discharging—the working efficiency thus obtained may be 97 per cent for the ampere-hours, and 87 per cent for the watt-hours. If, on the contrary, the cell be constantly charged up before being tested, then for the first few charges and discharges between the above limits, and with the same current density in charging and discharging, even the energy efficiency may be as high as 93 per cent; whereas, if the accumulator has been left for some weeks, then, although it was left charged, the energy efficiency for the first few charges and discharges will be as low as 70 per cent."

In general practice it has been found that the watt-hour efficiency of storage-battery plants, when in good condition, varies from 75 to 80 per cent. For instance, referring to the battery plant at the Edison Electric Company station in Boston, a series of tests made there show the battery installation to have an efficiency of 75 per cent.

Depreciation of Accumulators. The depreciation is claimed to be as low as 4 or 5 per cent per annum; but 7 per cent is a safer allowance to cover depreciation and renewals extending over long periods of time. During the first few years the depreciation may be practically nothing; but after five or ten years it will be considerable. These statements apply to *stationary* batteries in central stations or isolated plants. For *traction* or *automobile* service, which is much more severe, the life of storage batteries in some instances has not exceeded six months; and 3,000 to 5,000 miles total run is considered a good result in actual practice. For either stationary or vehicle storage batteries, the life of the positive plates is only half as great as that of the negatives. The figures given are based upon an average of the two.

It has been the practice of several storage battery manufacturers to insure their stationary battery equipments for 6 per cent per annum of their first total cost. This insurance is a maintenance contract calling for inspection and any repairs necessitated through normal use of cells.

TROUBLES AND REMEDIES

The most serious troubles which occur in storage batteries are *sulphating, buckling, disintegrating,* and *short-circuiting* of the plates. These can usually be avoided, or cured by proper treatment if they have not gone too far.

Sulphating. The normal chemical reaction which takes place in storage batteries is supposed to produce lead sulphate ($PbSO_4$) on both plates when they are discharged, their color being usually brown and gray, as already stated. But under certain circumstances a whitish scale forms on the plates, probably consisting of $Pb_2 SO_5$. Plates thus coated are said to be *sulphated.* This term is therefore somewhat ambiguous, since the formation of a certain proportion of ordinary lead sulphate ($PbSO_4$) is perfectly legitimate; but the word has acquired a special significance in this connection.

A plate is inactive, and practically incapable of being charged, when it is covered with this white coating or sulphate, which is a non-conductor.

The conditions under which this objectionable sulphating is likely to occur are as follows:

(*a*) A storage battery may be overdischarged—that is, run below the limits of voltage specified—and left in that condition for several hours.

(*b*) A storage battery may be left discharged for some time, even though these limits have not been exceeded.

(*c*) The electrolyte may be too strong.

(*d*) The electrolyte may be too hot (above 125° F.).

(*e*) A short circuit may cause sulphating, because the cell becomes discharged (on open circuit), and, when charging, it receives only a low charge compared with the other cells of the series. A battery may become overdischarged or remain discharged a long time, on account of leakage of current due to defective insulation of the cells or circuit; or the plates may become short-circuited by particles of the active material or foreign substances falling between them.

Sulphating may be removed by carefully scraping the plates. The faulty cells should then be charged at a low rate (about one-half normal) for a long period. In this way, by fully charging and only partially discharging the cells for a number of times, the unhealthy sulphate is gradually eliminated. When the cells are only slightly sulphated, the latter treatment is sufficient without scraping; when the cells are very badly sulphated, the charge should be at about one-quarter the normal rate for three days.

Adding to the electrolyte a small quantity of sodium sulphate, or carbonate, which latter is immediately converted into sodium sulphate, tends to hasten the cure of sulphated plates by decomposing or dissolving the unhealthy sulphate. This is not often used in practice, as a cell must be emptied and thoroughly washed, and fresh electrolyte added after the plates have been restored to their proper condition, before the cell can be used to advantage.

Sulphating not only reduces the capacity of lead storage batteries, but also uses up the active material by forming a scale which falls off or has to be removed. It also produces the following troubles:

Buckling. Buckling or warping of a plate, is caused by uneven action on the two surfaces; for example, a patch of white sulphate on one side of a plate will prevent the action from taking place there, so that the expansion and contraction of the active material on the other side, which occurs in normal working, will cause the plate to buckle. This might be so serious that it would be impossible to straighten the plate without breaking or cracking it; but, if taken in time, this may be accomplished by placing the warped plate between boards, and subjecting it to pressure in a screw or lever press. Striking the plate is objectionable, because it cracks or loosens the active material; but, if it should be necessary to straighten a plate in this way, a wooden mallet should be used very carefully, with flat boards laid under and over the plate. Buckling may be caused by an excessive rate of charging or discharging, as well as by sulphating.

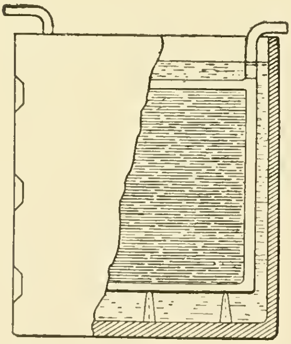
Disintegration. Some of the material may become loosened or entirely separated from the plates, as a result of various causes.

The chief of these is sulphating, which forms scales or blisters that are likely to fall off, thus gradually reducing the amount of active material and the capacity of the cell. Buckling also tends to disintegrate the plates. Contraction and expansion of the active material take place in normal working, and are increased by excessive rates or limits of charging and discharging. This constitutes another cause of disintegration, particularly in plates of the Faure type containing plugs or pellets of lead or lead oxide paste.

The fragments which fall from the plates not only involve a loss of material, but are also likely to extend across or gather between the plates, and cause a short circuit.

The positive plates are far more susceptible to and injured by these troubles than the negatives. The former are also more expensive to make; therefore it is to them that special attention should be directed in the management of storage batteries.

Short=Circuiting. Short-circuiting of a cell may be caused by conditions previously stated, and also by the collection of sediment at the bottom of the containing cell. The short-circuiting caused by the dropping in of foreign matter, or the bridging of the active materials, is prevented by the use of glass, rubber, or wooden separators.



F'g. 17. Glass Frame Support Used to Prevent Short-Circuiting by Sediment.

The short-circuiting of plates by the formation of sediment is prevented, or the chances of it are decreased, by raising the plates so that they clear the bottom of the containing cell. In small batteries this clearance is about an inch; in very large cells it is considerable, being about 6 inches; and large-sized plates, on account of their weight, are supported at the bottom by glass frames running lengthwise through the cell, as shown in Fig. 17.

This sediment should be watched carefully; and when it reaches a depth of 1 inch or more at the center of the cells, it should be removed. The usual method is to take out the plates, siphon the electrolyte off carefully, and then flush out the tanks until all the sediment is removed. If siphoning cannot be resorted to because of the absence of drop, a pump may be used, either of glass or of the bronze rotary type.

Troubles from Acid Spray. A storage battery gives off occasional bubbles of gas at almost any time or condition; but when nearly charged, the evolution becomes more rapid. These bubbles, as they break at the surface, throw minute particles of acid into the air, forming a fine spray which floats about. This spray not only corrodes the metallic connections and fittings in the battery room, but is also very irritating to the throat and lungs, causing an extremely disagreeable cough.

Glass covers are sometimes placed over cells to prevent the escape of fumes; but this is not advisable, as the glass becomes moist and will collect dust, thus forming a conducting surface over the cell.

Attempts have been made to do away with this spraying by placing an oil film (thin layer of oil) over the electrolyte; but this has the objection of interfering with hydrometers; in addition, it sticks to the surface of the plates when they are removed, and interferes with their conductivity on replacing them.

Another plan consists in spreading a layer of finely granulated cork over the surface of the liquid; but while this does not interfere with the hydrometer, it makes the cell look dirty.

The general practice is to depend almost entirely upon ventilation to get rid of the acid fumes; in fact, even forced ventilation is used. A blower forces fresh air into the room, which is provided with a free exhaust.

In connecting up the cells, it is advisable to use lead-covered copper cables, and to paint all connections with an acid-resisting paint, as these coverings protect the copper and prevent the formation and the dropping of copper salts into the cell.

Purity of the Electrolyte. This is very important, and great care should be taken to insure it. The electrolyte may have nitric acid present when formed (Planté) plates are used; and some chlorine, when Chloride negatives are used. In addition, iron may be present, due to the water or acid if the sulphuric acid is made from iron pyrites; it may also be present owing to the corrosion of iron fittings near the cells, some of the scale falling into the electrolyte. Similarly, some of the copper salt formed from the connections by this corrosive action may fall into the cell. Mercury may also be present as a result of the breakage of hydrometers or thermometers.

Other foreign substances might be present, but those named are the most harmful. Nitric acid, even in exceedingly small quantities, will cause disintegration of plates, as the supporting material is destroyed. Chlorine has a similar effect. Iron, mercury, and copper produce local action, and thus decrease the efficiency and ultimately the life of the cells. The electrolyte should be tested about once a week for these impurities; and if any of them are present, it should be drawn off and renewed. If nitric acid is present, it is even advisable to flush the cell with pure water.

TESTS

1. **Test for Chlorine.** Take a sample of the electrolyte, acidulate with nitric acid, and add a few drops of silver nitrate solution. If a curdy white precipitate forms, which is soluble in ammonium hydrate, chlorine is present in some of its compounds.

2. **Test for Iron.** Iron may appear in one of two forms, namely, ferrous or ferric salts. A small sample is taken, and some concentrated hydrochloric acid added, and then some potassium ferric cyanide; if a heavy blue precipitate forms, ferrous iron is present; if in very minute quantities, a deep blue-green discoloration results.

3. **Test for Ferric Salts.** To a sample of the electrolyte, add some hydrochloric acid and a few drops of ammonium thiocyanite; if a blood-red solution or precipitate is the result, ferric salts are present.

4. **Test for Copper.** To a sample of electrolyte, an excess of ammonium hydrate is added; if a rich blue solution is the result, copper is present. It is advisable to check the test by taking another sample and adding some potassium hydrate to it; if a blue precipitate is found which turns black upon boiling, it is additional proof of the presence of copper.

5. **Nitric Acid or its Compounds.** As these are injurious, even in very small quantities, it is advisable to make the following test, which is very sensitive: Some diphenylamine in concentrated sulphuric acid is added to the sample; if a deep blue color is the result, nitrates or nitrites are present.

6. **Test for Mercury.** Mercury may be present in two forms, mercurous or mercuric compounds. The *mercurous* compounds give a black precipitate with lime water, and a greenish precipitate with potassium iodide. The *mercuric* compounds give a yellow precipitate with lime water, and a red or scarlet precipitate with potassium iodide.

On account of possible difficulties with these various impurities, the following are recommended:

1. Test every carboy of sulphuric acid before using.
2. Concentrated sulphuric acid should not be kept around, as it may be used by mistake, which would ruin the plates.
3. Only distilled water from carboys should be used, and not from barrels, as in the latter case it may be contaminated by organic matter.
4. Water from the city mains is never to be used unless the amount of impurities which it contains is very small.
5. When testing with hydrometer for specific gravity, the battery should be fully charged, and tests *always made at the same temperature, or temperature changes should be corrected for,* because the specific gravity of the electrolyte falls with increase of temperature. The specific gravity changes due to temperature are given in Table VII.

TABLE VII

Specific Gravity of Dilute Sulphuric Acid at Various Temperatures

TEMPERATURES	30° F.	40° F.	50° F.	60° F.	70° F.	80° F.	90° F.	100° F.	110° F.
Sp. gr.	1.1593	1.1562	1.1531	1.1500	1.1469	1.1438	1.1407	1.1376	1.1345
"	1.2096	1.2064	1.2032	1.2000	1.1968	1.1936	1.1904	1.1872	1.1840
"	1.2620	1.2590	1.2530	1.2500	1.2470	1.2440	1.2410	1.2380	1.2350
"	1.3090	1.3060	1.3030	1.3000	1.2990	1.2940	1.2910	1.2880	1.2850
"	1.3620	1.3580	1.3540	1.3500	1.3460	1.3420	1.3380	1.3340	1.3300
"	1.4144	1.4076	1.4048	1.4000	1.3952	1.3904	1.3856	1.3808	1.3768

Putting the Battery out of Commission. If, for any reason, the battery is to be but occasionally used, or the discharge is to be at a very low rate, a weekly freshening charge to full capacity at normal rate should be given.

It frequently happens in practice that a storage battery equipment is put out of commission for a lengthy period (for instance, in most summer or winter resorts, the battery may be used for one-half of the year only). In such cases the procedure is as follows: First give the battery a complete charge at normal rate, then siphon off the electrolyte into carefully cleaned carboys (as it may be used again); and, as each cell is emptied, *immediately* refill it with pure water, to prevent the charged negative from heating in the air, as this would result in loss of capacity. When the acid has been drawn from all cells and replaced with water, begin discharging the battery, and continue until the voltage falls to or below one volt per cell at normal load (rate); when this point has been reached, the water should be drawn off. In this condition the battery may stand without further attention until it is to be put again into service; and to do this, proceed in the same manner as when the battery was originally put into use.

If, during discharge, when water has replaced electrolyte, the battery shows a tendency to get hot (100°F.), add colder water.

COMMERCIAL APPLICATIONS

The function of a storage battery is to receive electrical energy at one time or place, and to give it out at some other time or place. The principal uses are the following:

1. To furnish portable electrical apparatus with power.
2. To make up for fluctuations, and thus steady the voltage and load on the generator.
3. To furnish energy during certain hours of the day or night, and enable the generating machinery to be stopped.
4. To aid the generating plant in carrying the maximum load (peak), which usually exists for only an hour or two.
5. To make the load on engines or prime movers more uniform, by charging the battery when the load is light.
6. To transform from a higher to a lower potential by charging the cells in series, and discharging them in parallel, or *vice-versa.*
7. To subdivide the voltage, and enable a three- or a five-wire system to be operated from a single generator.
8. To supply current from local centers or substations.
9. To supply current to electrically-driven vehicles.
10. As sources of current in telephone and telegraph systems.
11. For car-lighting purposes.
12. As sources of constant potential and current in electrical laboratories.

Portable Storage Batteries. The storage or the primary battery is practically the only means of supply for portable electric lamps or for those not connected to a dynamo even when they are not portable.

The various manufacturers furnish portable forms of storage batteries. The Gould Storage Battery Company's portable battery

(Fig. 18) is arranged in a case made as a hard rubber jar, lead-lined box, or glazed earthenware jar, over which is placed a rubber gasket, and then a wooden cover clamped in place by U-shaped straps passing around the containing vessel. For ventilation in charging, the cover has threaded holes, which, when the battery is in use, are closed with hard rubber stoppers. The usual number of cells in a case is from one to five, although they are made up in larger numbers if desired. The batteries are rated at 2 volts per cell.

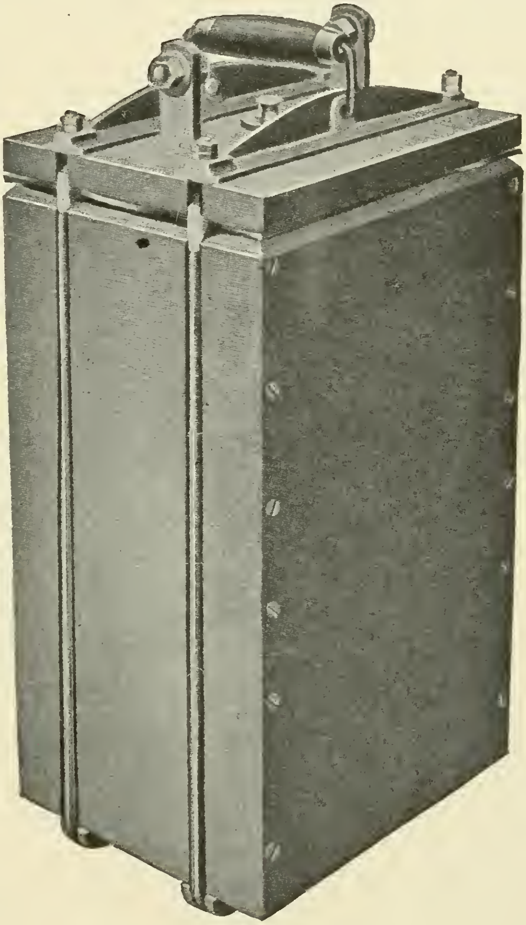


Fig. 18. Gould Portable Storage Battery.

A serious objection to portable storage batteries is their great weight. For example, a standard size weighing 100 lbs. yields 5 amperes at ten volts, or fifty watts, for ten hours—just enough to feed a 16-candle-power lamp. The total discharge is 500 watt-hours or two-thirds of one horse-power-hour. The special forms of battery used in automobiles give about twice this output for the same weight.

This weight is almost prohibitive to portability, except for automobiles, railway train lighting, and special purposes.

Portable batteries, for example, are used for feeding small motors, lamps, etc., for medical or dental purposes, in which cases their weight is not a serious difficulty, in view of the importance of the work and the small amount of energy required. Another special field for very small batteries is the theatrical application, for which they are carried by performers. Storage batteries are also extensively used as sources of power to drive small fan and kinetoscope motors.

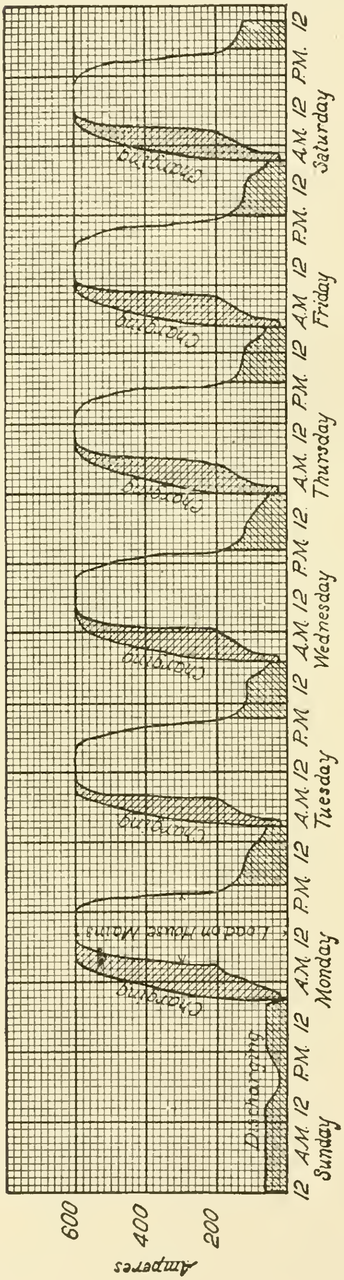


Fig. 19. Load Curve of Astor Building, New York City.

Storage Batteries for Preventing Fluctuations due to unsteadiness in the driving power or in the load, as with elevators, are often applied successfully. A dynamo driven by a gas engine for example, may vary periodically in speed because of the explosive action of the gas in the cylinder; and a battery connected in parallel with the dynamo will have the effect of steadying the voltage. A storage battery is generally installed in connection with a small gas-engine or steam-engine lighting plant, to enable the engine to be stopped for a considerable portion of the time, and thus save labor and attention, in which case the battery may also act to prevent fluctuations. A windmill electric-lighting plant must have an accumulator or some other means of storing energy, not only to eliminate fluctuations in speed, which are continually occurring, but also to bridge over the considerable periods of calm weather.

To Furnish Energy during Certain Portions of the Day or Night. In almost every electric-lighting plant, there are long periods during the day and late at night when the number of lamps lighted is so small that it may not pay to run the generating machinery.

For example, Fig. 19 is a load diagram showing the weekly output of the electric plant of the Astor Building in New York City. The generator plant runs from 3 a.m. to 8 p.m. each day, the battery being charged from 3 a.m. to 11 a.m.; and when the generating plant is shut down at 8 p.m. the battery carries the entire load from then until 3 a.m., when the plant is started up again. Saturday nights the plant is shut down at eight o'clock, and the battery furnishes all the power required from then until Monday morning at 3. This enables the plant to be operated by two gangs or shifts, practically no labor being required for the remaining seven hours, as the battery carries the load, and the machinery is stopped entirely all day Sunday, giving a stretch of thirty-one hours once a week, and seven hours each night for cleaning and repairs. In a hotel or residence, or on board a yacht, it may be desirable to stop the machinery and avoid the vibration and noise during the night.

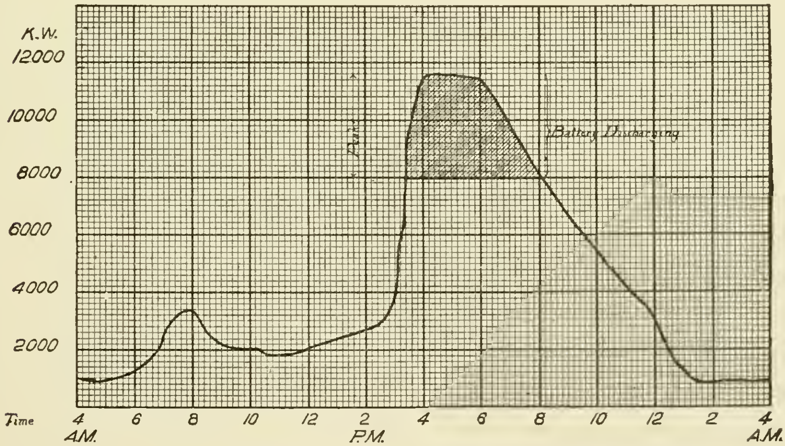


Fig. 20. Load Curve Showing "Peak" of Load Carried by Storage Battery.

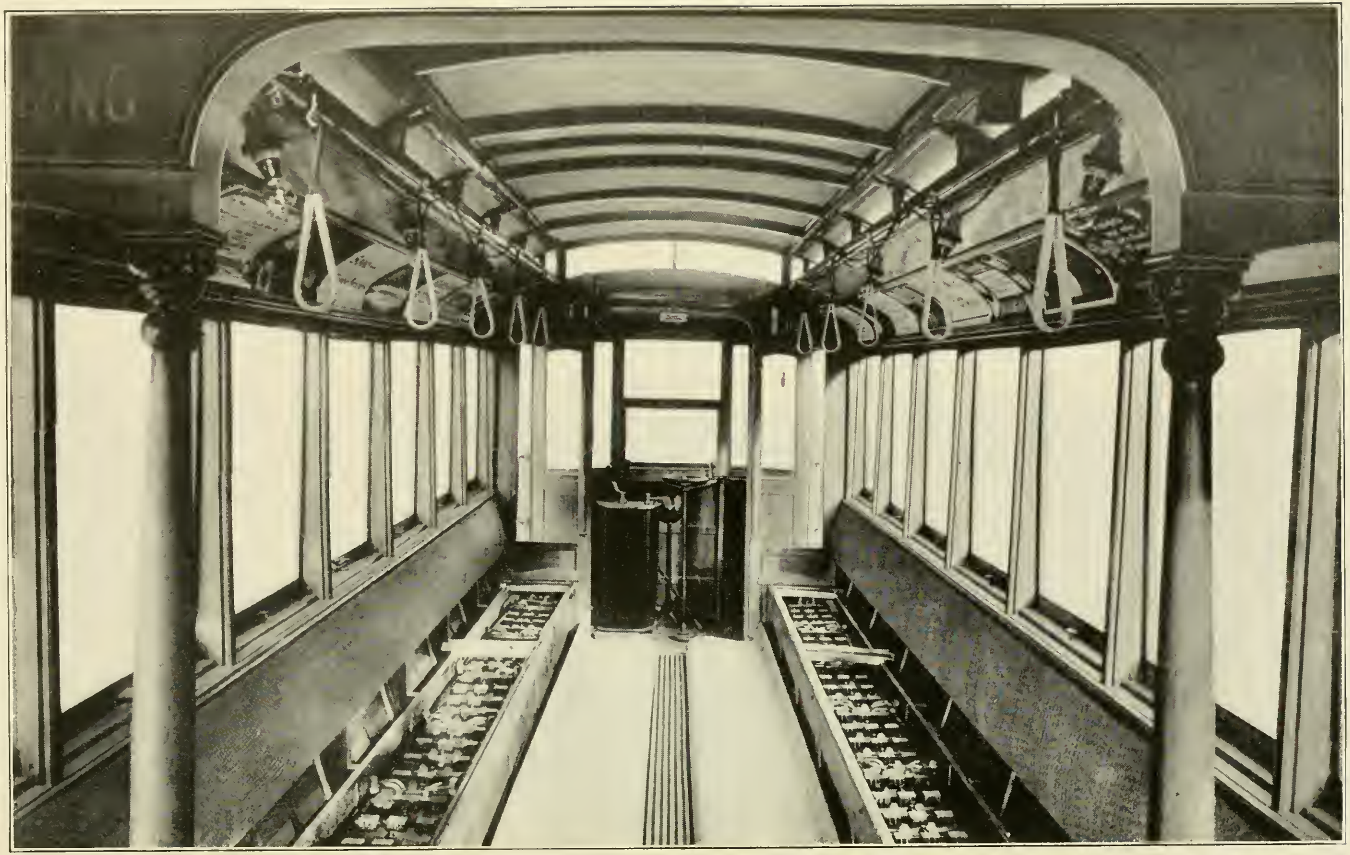
Storage Batteries to Aid in Carrying the Maximum Load. Assume, in the case of the load diagram shown in Fig. 20, that the generating machinery is capable of supplying 8,000 kilowatts, and that a storage battery is used to furnish the remaining 3,600 kilowatts at the time of maximum load—that is, the *peak* of the load diagram. This simply means that batteries are substituted for a certain portion of the machinery plant, and the question is whether or not the substitution is of any advantage.

The first cost of a battery for a given rate of output depends simply upon the time of discharge. Batteries usually have a normal period of discharge of about 8 hours, at which rate the price of accumulators to furnish a given number of watts would be 3 to 5 times as great as that of the equivalent boilers, engines, and dynamos combined; but if the time of discharge is reduced to about 2 or 3 hours, the costs are about equal; and with a still higher rate, the cost of batteries would be less.

As a matter of fact, the storage battery secures other advantages, so that the total gain may be very important. For example, there is a reserve supply in case of accident; and the load may be made more uniform, as will now be explained.

Storage Batteries to Maintain Uniform Loads on Engines. Steam engines are very inefficient at light loads, and this fact often causes serious losses, especially in electric-lighting plants. Judicious selection of the number and sizes of the engines enables them to be worked in most cases at a considerable fraction of their full capacity nearly all the time. Nevertheless the storage battery gives greater flexibility to the plant, and renders it easy to increase the economy of the engines by making their loads still more uniform and nearer to their full capacities while they are running. The engines can be made to have a uniform full load, the battery being charged when the external load is light, and the battery taking the peak of the load when it is heavy.

Storage Batteries Used as Transformers. If the cells of a battery are arranged in series while being charged, and in parallel for discharging, a high voltage will be required for charging, and a low voltage will be given out. The amounts of energy measured in watt-hours are the same, less the loss of about 25 per cent which always occurs in accumulators; the result is similar to that obtained by an alternating-current transformer or motor-dynamo, but is less efficient. As an example, the equipment used at the Brooklyn Navy



INTERIOR OF STORAGE BATTERY ELECTRIC CAR
Seats removed showing location of storage batteries
Courtesy of Gould Storage Battery Company

Yard may be mentioned. It consists of about 250 small cells connected up in series parallel of 5 sets of 50 cells each and charged on a 110-volt circuit. When discharged, they are connected up all in series, and give about 500 volts, but with very small current. This equipment is used to furnish 500 volts for the *insulation test* of cables, and therefore requires little or no current.

Storage Batteries Used for Subdividing Voltage. The most important practical case is that in which a dynamo of 220 volts charges a battery of corresponding potential, a three-wire system being supplied from the battery, the neutral wire of which is connected to the middle point of the battery, as represented in Fig. 21.

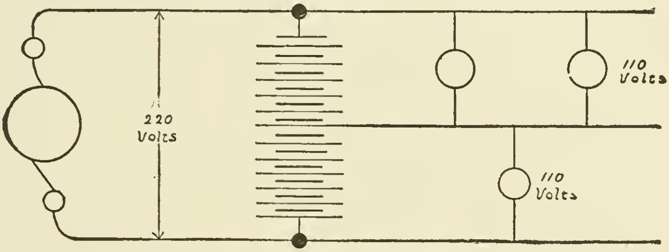


Fig. 21. Battery Used to Subdivide Voltage.

This arrangement avoids the necessity of running two dynamos, and allows the battery to be placed in a substation near the district to be supplied, so that it is necessary to run only two conductors to that point instead of three. The same principle may be applied to the five-wire system. When used in this manner, each side of the system requires its individual end cells and regulators.

The Hartford Electric Light Company was one of the first in this country to introduce the modern method of high-tension transmission, with low-tension 3-wire distribution.

The auxiliary battery used in connection with this equipment consists of 130 Chloride accumulators (65 on a side), each cell containing 31 negatives and 30 positive plates, each $15\frac{1}{2}$ by 31 inches, placed in lead-lined tanks measuring $58\frac{1}{4}$ by $21\frac{1}{2}$ by $43\frac{7}{8}$ inches. Fig. 22 is a diagram showing the general plan of the system. The power is transmitted 10.8 miles from the Farmington River Power Station to the Pearl Street Station, in Hartford, by means of step-up transformers, a 10,000-volt transmission line, and step-down transformers for distribution. From Pearl Street Station to State

Street, a distance of 3,000 feet, the current is transmitted at 2,400 volts, at which latter point, by means of step-down transformers and rotary converter, the storage battery is charged and the current distributed over a low-tension three-wire system.

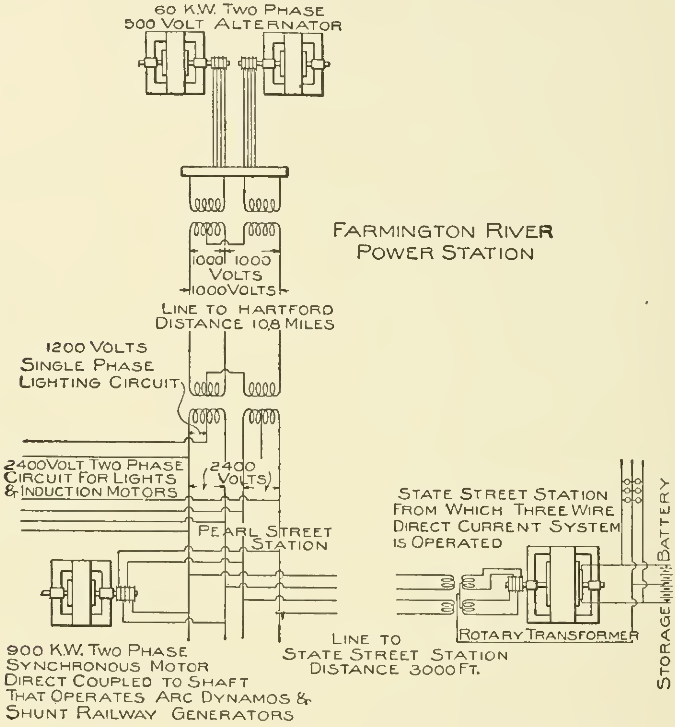


Fig. 22. Plan of Farmington River-Hartford Distribution System.

Storage Battery for Substations. The plan of installing battery plants at local centers, which are charged from the main station, enables some of the conductors to be saved in a three- or five-wire system, as already stated. It also makes it possible to reduce the size of these conductors, because the current which flows over them can be kept practically constant, so that it is not necessary to have them large enough to carry the maximum current consumed by the lamps, etc., which may be several times its average value. The generating machinery has the same steady load as if the battery were located near it.

The batteries at the various substations may be connected and charged in series or in parallel The former plan would require far less copper in the conductors, since the voltage is multiplied by the number of batteries in series, and the current is the same as for a single battery. On the other hand, this great difference of potential would exist between the first and the last batteries of the series; and if either of these became grounded any person connected to the earth and touching a wire supplied by the other battery would receive a shock due to the total voltage.

An excellent example of a storage battery substation is the Bowling Green Plant of the New York Edison Company. The Bowling Green Station furnishes an auxiliary supply of current directly from the battery, enabling the feeders, extended as tie-feeders into the Bowling Green building, to be used as distributing feeders to the system from both the Duane Street and Bowling Green Stations. While acting as an auxiliary supply to the general system, the battery also takes care of the distribution of current to the extensive installation in the Bowling Green building itself. The supply of current to charge the battery is taken from the Duane Street Station, about a mile distant, over four tie-feeders equipped with controllable disconnective switchboxes on the Bowker-Van Vleck system. This enables them to be used as tie-feeders by disconnecting them from the general system during the hours of light load, and as distributing feeders during the hours of maximum load, when they feed current into the system from each end. A considerable saving is thus effected in the investment, because costly feeders are not required to supply the maximum load to a distant part of the system.

This installation of an auxiliary source of current supply in the lower district makes it possible to shut down the generators in the Duane Street Station during the hours of minimum load, the supply of current to the district below 8th Street being derived from the battery plants at Bowling Green and 12th Street Stations, supplemented, if desired, by the supply of current from the 26th Street Station, over the tie-lines to 12th Street Station, whence the current is distributed through boosters raising it to the required potential, over the tie-feeders to the Duane Street Station switchboard. The battery and operating rooms of the Bowling Green

Station are located in the sub-basement of the Bowling Green Office Building. Vitrified hollow tile for conducting the feeder cables are laid under the battery-room floor, which consists of glazed white tile. Drains to carry off the water or acid run in the aisles between the cells, and lead to small cesspools which discharge into a lead drain-pipe.

The battery consists of 150 Chloride cells, 75 in series on each side of the three-wire system. The cells consist of wooden tanks, $40\frac{3}{4}$ by $21\frac{1}{2}$ by $30\frac{1}{2}$ inches, treated with an acid-proof paint and lead-lined, each containing 14 positive and 15 negative plates $15\frac{1}{2}$ inches wide by 31 inches high. Each tank is supported on four petticoat porcelain insulators resting upon 6-inch glazed tiles.

The plates are suspended in the tanks by shoulders resting upon sheets of heavy glass, which stand upon lead saddles in the bottoms of the tanks. The cells are connected by welding the plate terminals to lead bus-bars, no mechanical connections being used.

Twenty of the end cells on each side of the system are used for regulating, being separately connected to contact points on the regulating switches, which carry movable contacts operated by a screw. The potential is raised or lowered by cutting in or cutting out the regulating cells. Two regulating switches are connected in multiple on the positive, and two on the negative, side, to permit of discharging at two potentials, or to enable the battery to be charged and discharged simultaneously. The conductors between each series of cells, and between the regulating cells and the regulating switches, consist of copper bars 3 inches wide by $\frac{1}{2}$ inch thick. These bars are supported on porcelain insulators resting in hangers. The connections of this equipment are shown in Fig. 23.

The capacities of the battery at various rates of discharge are:

2,000 amperes per side for 1 hour.
1,000 amperes per side for 3 hours.
400 amperes per side for 8 hours.

Provision has been made in the battery-room, for the installation of a duplicate battery, which can be placed over the present plant. The booster is used to raise the voltage from that of the system to that required for charging the battery. The booster can be used also to raise the voltage of discharge for feeding some distant point of the system at a higher potential than would normally be required. The machine consists of one positive and one negative dynamo at each end of a common shaft driven by two motors. Each dynamo has a capacity of 1,200 amperes, and a range of pressure up to 60 volts.

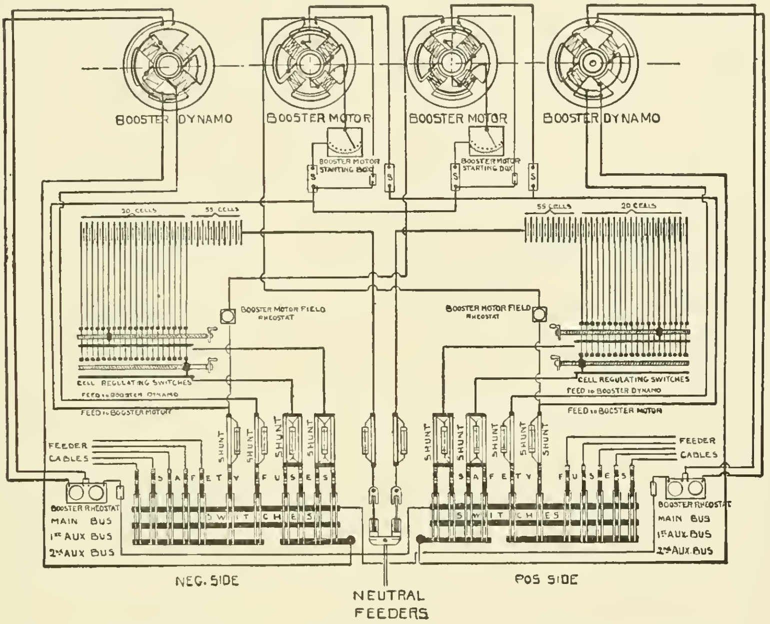


Fig. 23. Connections of the Bowling Green Storage Battery Substation.

Storage Batteries Used for Two or More of the Above-Named Purposes. Each of the different uses has been considered separately to avoid confusion, but in most cases the storage battery is adopted in order to secure several advantages. By thus combining different applications, the plant is rendered not only more economical, but also more flexible. For example, the battery may be utilized to help out the generating machinery at times of heavy load, or when the latter is partially or wholly disabled. It often happens that it is difficult to produce or maintain sufficient steam pressure, owing to poor draft or other conditions, in which event a battery enables the boilers to be temporarily relieved of some or all of the drain upon them while the pressure is being raised to the proper point. It may also be necessary or desirable to shut down the machinery or a portion of it, temporarily, in order to make some repair or adjustment. It is also possible to feed some of the circuits from the battery while the others may be supplied at a higher or lower voltage by the machinery. In these and many other ways the storage battery may be a convenient adjunct to an electrical system. The fact that it is so radically different from the machinery in its nature and action, makes it very unlikely that the entire plant will be crippled at any one time, since the two sources of current are not exposed to the same dangers. An accident to the steam piping, for instance, might shut down all the machinery, but probably it would not affect the battery; and, *vice-versa,* an accident to the latter is not likely to extend to the former.

As an example of this application of the storage battery to several purposes, the following case may be cited:

The installation of storage batteries at the power house of the Woronoco Street Railway Company, in Westfield, Mass., presents features of special interest. After considering various methods of increasing the power-house capacity, rendered necessary by the construction of an extension of the line, it was decided that the storage battery offered the greatest advantages.

The station equipment consists of two 75-kilowatt multipolar generators belted to two 120-horse-power, high-speed, simple, non-condensing engines, steam being furnished by two 90-horse-power return tubular boilers.

The battery consists of 264 Chloride Accumulator cells, Type F–11, in glass jars of Type F–13, permitting an increase of 20 per cent by the addition of one pair of plates in each cell, and is installed in a small brick extension to the power house. The cells are located in one tier, each cell being supported on a sand tray resting on four glass insulators. The foundation for each row of cells consists of two stringers of wood suitably braced and supported on brick piers. This battery was not installed as a voltage regulator, the feeder system being so designed that the drop on the line is only a small amount.

By means of the battery, the load on the machinery is reduced within the capacity of one unit, leaving the second one as a reserve in case of an accident or an unusually heavy load. Without the battery, both machines would be needed nearly all the time.

The economy of operation due to using one unit instead of two, is clearly shown by the following station records:

	Date, 1899.	Lbs. coal.	Output kw.-hrs.	Lbs. coal. per kw.-hr.
With battery	Oct. 25–27	16,250	3,032	5.36
Without battery	Oct. 28	6,250	981	6.37

This shows an increase in the coal consumption, of 19 per cent, on the day when the operation of the battery was discontinued. The plant is also noteworthy from the fact that the station attendance is reduced to one man per shift, the engineer doing his own firing. This arrangement could not have been continued under the conditions of increased load, had it not been for the improved regulation and reduction of coal handling, and especially the increased reliability of operation secured by the battery.

On several occasions the battery has been called upon to carry the entire load of the system for an hour or so, during a temporary shut-down of the rest of the plant, as well as early in the morning or late at night, when only one or two cars are in operation.

Storage Batteries for Propelling Vehicles and Boats. The storage battery is usually about 35 per cent of the total weight in the modern electric automobile; and even with this great proportion, the distance run on one charge is seldom more than from 20 to 40 miles at a speed of about ten miles per hour, and that only on comparatively smooth roads. The ordinary battery equipment consists of about 44 cells of 108 ampere-hours capacity with an average discharge voltage of about 1.9.

In cities or where the roads are good, with charging stations close at hand, the electric automobile is superior to the gasoline types on account of the absence of explosive vapors, with the accompanying odor and noise. But for general touring they are not so handy, on account of the limited capacity of the battery.

The application of the storage battery to the street-car, while presenting such great advantages as the entire absence of poles and overhead wires, has not been a commercial success, mainly on account of the mechanical weakness of the plates, which are not able to stand the jolting and jarring or the rush of current due to frequent starts and stops. Another objectionable feature is the escape of acid fumes into the car, producing throat irritations and coughs among the passengers, although this is overcome by the use of fans.

The storage battery has been comparatively successful as a source of power in submarine boats, being charged while the vessel is on the surface, and discharged to run electric motors and lights when the vessel is manœuvering under the surface.

Storage Batteries in Telephone and Telegraph Systems. Since the adoption of the central battery systems by telephone companies, the use of the storage battery for this purpose has become very common, its advantages over the primary cell being as follows: Lower first cost; smaller space required (about $\frac{1}{4}$ of that occupied by an equivalent primary battery); greater constancy of E. M. F. and lower internal resistance; absence of the annoying *creeping salts;* and rapidity of recharge. The cost of storage-battery maintenance is about $\frac{1}{8}$ that of the primary cell.

In telephone work, the battery is installed in the district station, and charged when the line is not in use, from either a street connection or a generator in the station. When the line is in use for conversation, the charging current is automatically cut off, and the battery alone switched into service.

The storage battery in telephone work has become so important that the following description of a typical installation is given.

In the Filbert Street Exchange of the Philadelphia Bell Telephone Company, there are two generating units, forming a duplicate plant, each consisting of one engine, directly connected to a 30-kilowatt, 110-volt dynamo. These machines are run on alternate days, and are used for lighting the building and for furnishing power at 110 volts to various motor-generators. The latter comprise two 1.5-kilowatt machines for charging a 20-volt battery, one 1.5-kilowatt machine for charging an 8-volt battery; one 500-watt machine for charging a 4-volt battery; and two $\frac{1}{4}$-horse-power 75-volt alternating-current motor-dynamos for ringing call bells. Only one machine is installed for the 8-volt battery, and one for the 4-volt battery. Both batteries are in duplicate. To avoid a possible breakdown, a rheostat is furnished, so that the batteries of lower voltage can be charged from batteries or motor-generators of higher voltage. All machines are protected by automatic cut-outs.

The 20-volt battery consists of ten Chloride Accumulators having a capacity of about 1,000 ampere-hours, which furnish all the current needed by the subscribers for talking and for calling up the central office. The 8-volt batteries, in duplicate, consist of four cells, each having a capacity of 2,400 ampere-hours. This battery furnishes current for the "disconnect" signals on the operator's cords, and for the relays which cut out the subscriber's lamp signal when the operator answers his call, by plugging into the jack corresponding to the lamp signal.

Half the drop in potential of the 8-volt battery is in the 4-volt lamp, and the other half in the cut-out relay. This battery is in duplicate, so that one can be charged while the other is being discharged. This avoids danger of burning out the lamps, as the voltage of the battery is raised from 8 to 10 volts during charging.

Each of the duplicate 4-volt batteries comprises six 13-cells arranged in two sets. One of these sets consists of four cells, two in series, two in multiple; the other of two cells. The two extra cells are needed on one of the batteries to supply current for the operator's transmitters. The latter is arranged to furnish a current of four volts or two volts as desired. The 4-volt battery also furnishes all current for the lamp signals, which light when a subscriber takes his telephone off the hook. This lamp is put out when the operator answers the call. This battery also is made in duplicate, one being charged while the other is discharged, to avoid burning out the lamp from the higher voltage during charge.

Storage Batteries for Train Illumination. When cars are lighted by oil or gas lamps, these, owing to their size, and the heat produced by them, can be installed only in certain places, so that the distribution of light is not general, besides which, the heat and odor given off by the lamps are objectionable. The inflammable character of the illuminants involves great danger of explosion or fire in case of a train wreck. The absence of these disagreeable and dangerous features in electric lighting, is what has made its application so desirable in traction work.

Several methods of electric illumination have been tried on railroad trains. In one of the simplest of these, a small dynamo on the locomotive truck, or one perched above the boiler, is driven by a small steam turbine. While this is an economical method, it has the objection, that when the locomotive is uncoupled, the cars must be illuminated by some other means.

For this reason, the storage-battery system of supply has been adopted. One of the most successful methods is the "Axle Light" system. This, as its name implies, derives the motive power for its dynamo from the car axle. The mechanism is suspended from the bottom of the car, and is completely encased, so as to be dust-proof and waterproof. It comprises a small dynamo driven from a pulley on the axle of the car by means of a friction coupling.

The dynamo and driving mechanism are shown in Fig. 24. The former generates from 32 to 40 volts, depending upon the speed of the train, provided that it exceeds 15 miles per hour, the dynamo being then automatically connected to the battery and lamp circuit. An automatic device rectifies the direction of current, so that even though the direction of rotation is reversed, the battery is always charged in the proper direction. A variable resistance in series with the field coils is automatically adjusted by a small motor, so that even at high speed the normal limit of voltage is not exceeded.

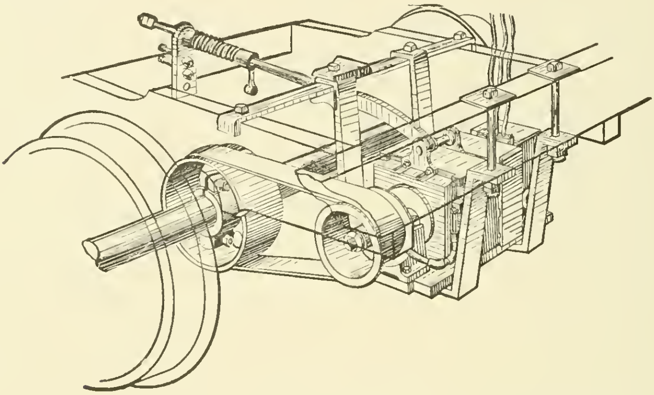


Fig. 24. Method of Suspension Used by the "Axle Light" System.

The lamps are 16-candle-power at 30 volts, the filaments being short and heavy so that they are not injured by vibration.

After the storage battery has been charged, it acts in parallel with the dynamo, and avoids fluctuations in voltage. When the car stops, the dynamo is automatically cut out, and the full supply of current is furnished by the battery, which is large enough for a ten-hour supply at full load.

Storage Batteries for Electrical Laboratories. The great advantage of this source of power in electrical laboratories, is the fact that any variation in the voltage is very gradual, and by the simple regulation of a rheostat in series with the battery, the operator can keep his voltage and current absolutely constant while a test or calibration is being made. When a large current is wanted, as in the case of ammeter calibration, the cells may be connected in parallel and discharged through a low resistance, thus cutting down the energy required for the test. A storage battery may also be used to step up the voltage, the cells being connected in parallel groups for charging, and in series for discharging.

The special arrangement shown in Fig. 25 consists of a storage battery *S.B.*, the charging current for which is regulated by a bank of incandescent lamps *L.* Where a large-capacity battery is employed, a rheostat or motor-dynamo can be substituted for the lamps. In the instance shown, four distinct operations may be carried on simul-

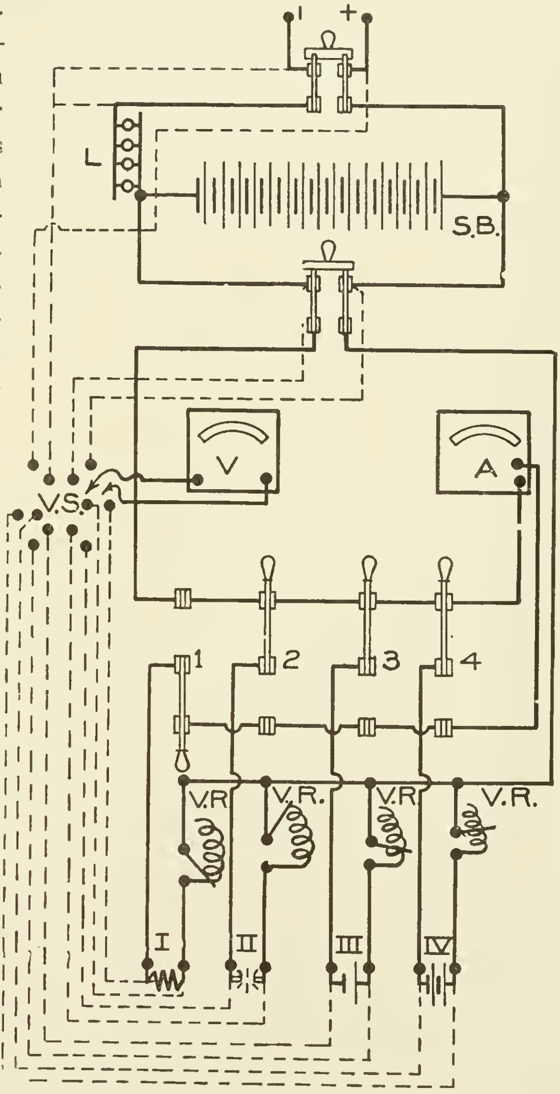


Fig. 25. Diagram of Connections of a Laboratory Equipment Arranged to Supply Current for Four Independent Operations.

taneously, without having one interfere with the other. Each one of the circuits is supplied with a regulating device *V. R.*, so that any desired current density is obtainable at the electrodes of the experimental devices I, II, III, and IV. The arrangement of the voltmeter circuits is such that the voltage of each individual circuit can be readily obtained through the use of the twelve-point voltmeter switch at *V. S.* The switching arrangement is such that by means

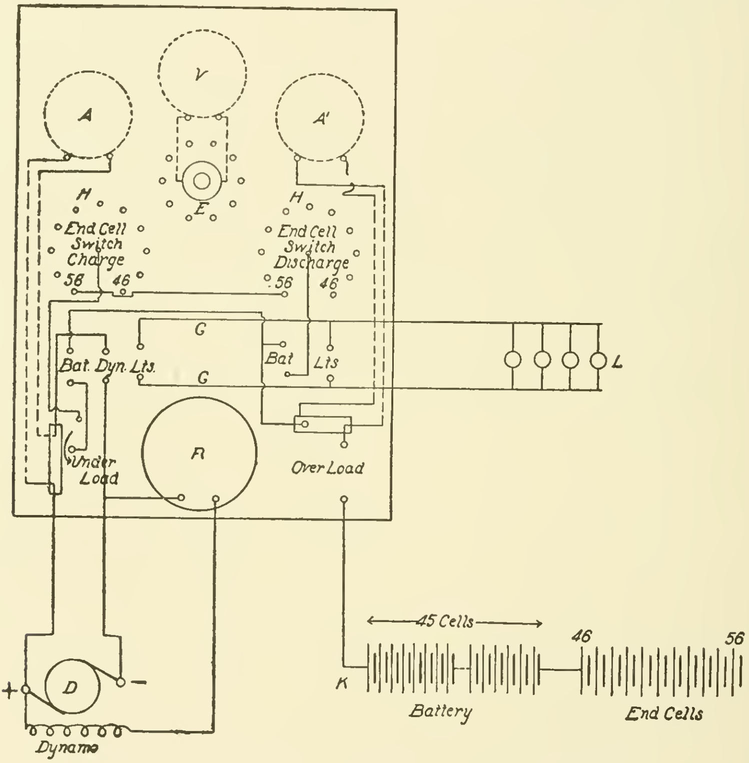


Fig. 26. Switchboard, Dynamo, and Battery Connections.

of one ammeter *A*, separate readings of the current in each branch circuit may be made, or the total current read. For example, with the switches as shown in the figure, the current flowing through the first apparatus consisting of a resistance furnace is being measured. If switch 1 were thrown in the opposite direction, and switch 2 had its position reversed, the current of group II would be shown by the ammeter. If all the switches were placed in the same position as switch 1, the ammeter would indicate the total current drawn by the four pieces of experimental apparatus.

Connection and Regulation of Storage Batteries. The complete control of a battery in an electric-lighting plant requires provision to be made for feeding the lamps, etc., from either the dynamo or battery separately, or from the two working in parallel; and it should be possible to charge the battery at the same time that lamps are being supplied. To accomplish these results requires three switches—one to connect the battery to the dynamo, one to connect the lamps to the dynamo, and one to connect the lamps to the battery. In some plants the second switch is omitted, because the lamps are always fed by the battery alone, the latter being charged during the day, when no lamps are in use. However, it would seem desirable to have all three switches in every plant in order to be able at least

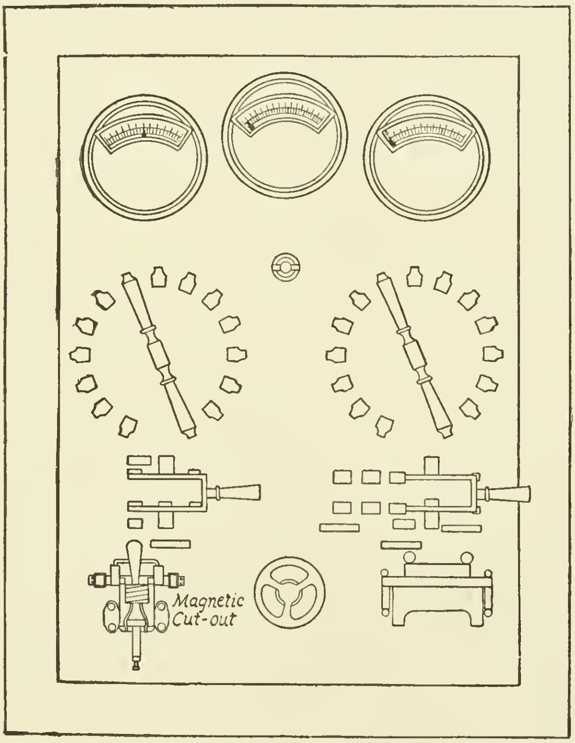


Fig. 27. Face of Switchboard.

to supply lamps and charge the battery at any time. In the battery circuit, there should be an ampere-meter having a scale on both sides of zero, so that it shows whether the battery is being charged or discharged, as well as the value of the current. Another similar ampere-meter is required in the circuit between the dynamo and the battery, to show the direction and amount of current. A third ampere-meter is desirable in the lamp circuit, to show the total current supplied to the lamps; but it need indicate only on one side of zero, since the current there always flows in the same direction. A voltmeter is required with a three-way switch, which enable it to be connected to the dynamo, battery, or lamps respectively.

An automatic overload switch must be inserted in the battery circuit so as to open or introduce resistance into the circuit when the current becomes excessive. An automatic cut-out is required between the dynamo and the battery to open the circuit when the charging current falls below a certain value, and thus avoid any danger of the battery discharging through the dynamo, if from any cause the E. M. F. of the latter drops below that of the former. This completes the ordinary measuring and circuit-controlling apparatus employed in connection with storage batteries. The arrangement is shown diagrammatically in Fig. 26, in which *A* and A^1 are the two ampere-meters, the third one being omitted in this case; *V* is the voltmeter; *E* the voltmeter switch to connect to the dynamo, battery, or lamps as desired; *G* the bus-bars; *L*, lamps; *D*, dynamo; *R*, rheostat in field-circuit of dynamo.

The regulating device consists of eleven end-cells, which are connected to corresponding contacts on the end-cell switches (Fig. 26). But as the drawing of these connections would complicate the figure, they have been omitted. Fig. 27 shows the switchboard with these devices mounted upon it.

Parallel Charge, Series Discharge. With batteries of small capacity, where it is not advisable or convenient to raise the generator voltage in order to charge all the cells in a single series, it is usual to divide the battery into two parts and charge each half of the battery individually, through a resistance from the main lines. This method is inefficient, however, and should be employed only with small equipments. Fig. 28 shows a diagram of connection for charging in this manner, and coupling the two halves of the battery in series during discharge, the discharge voltage being also regulated by resistance, there being no end cells employed.

Regulation of Storage Batteries. This is one of the most troublesome problems involved in the practical use of storage batteries. It arises from the fact that the voltage falls continually from the beginning to the end of discharge. To be sure, this decline is gradual; but its total value is large, being from about 2.2 to about 1.8 volts, which is a decrease of nearly 18 per cent.

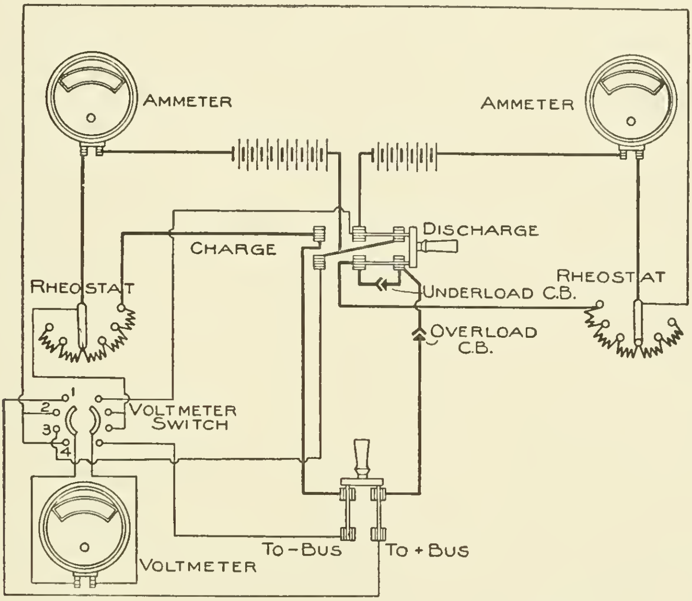


Fig. 28. Connections for Parallel Charge, Series Discharge.

In order to maintain a constant voltage, the usual plan is to have a number of extra cells, which are successively switched into circuit as the potential falls. These reserve cells and the switches which control them are represented in Fig. 26.

The contact-pieces of these switches must be made in such a way that they do not short-circuit the cells as they pass from one point to the next. This is accomplished by splitting the movable contact arm into two parts, between which a certain amount of resistance is introduced, so that when the two parts happen to rest on two adjacent contact-points, the resistance prevents the cell which is connected to these two points from being short-circuited, and also avoids breaking the circuit.

The number of extra cells depends upon conditions; for 110-volt lamps, it would require 51 cells to obtain 112.2 volts when fully charged and giving 2.2 volts each, assuming the drop on the conductors at 2 per cent. When the battery becomes discharged. and its potential falls to 1.8 volts per element, 10 additional cells, or 61 in all, would be needed. These would yield 111.8 volts, assuming the average potential of the reserve cells to be 2 volts, since they have not been discharged to the same extent as the original battery. If the drop on the conductors is 10 per cent of the lamp voltage, the potential at the battery will have to be 110 + 11 = 121. This will necessitate 4 more elements, or a total of 65, when the 51 original cells are fully discharged to 1.8 volts, and the 14 extra cells give 2 volts each.

For a three-wire system, the above figures should, of course, be doubled. This switching of extra cells into and out of the circuit obviously results in discharging them unequally; hence they require to be charged to a corresponding extent. This is accomplished by successively cutting the cells out of circuit as soon as they become fully charged, the last cell which was put into the circuit being fully charged in the shortest time, and so on. The amount of charge is determined by the methods already given. If the cells employed are not injured by overcharging, they may be left in circuit until the entire battery is fully charged. This saves the trouble of operating the switch; but it is wasteful of energy, since the full counter-E. M. F. and resistance of the charged cells must be overcome, which requires about 2.5 volts more per element. The switches might be operated automatically by a voltage regulator or by clockwork.

REGULATION OF GENERATOR IN CHARGING STORAGE BATTERIES

The variation in E. M. F. which occurs in accumulators renders it somewhat difficult to regulate the generators employed to charge them. A constant potential will give a decreasing rate of charge, owing to the gradual rise in counter-E. M. F. This is advantageous in that it enables the cells to receive a larger charge; but the increase in their voltage is so great that it is practically necessary to regulate the charging potential. In practice it is customary to maintain the charging current approximately constant for considerable periods of time; otherwise it would be difficult to determine the quantity of energy put into the battery, and its efficiency. When extra cells are used, they facilitate the regulation of the generator, since they are gradually cut out as the E. M. F. rises.

If the lamps are supplied at the same time that the battery is being charged, some provision must be made for the fact that it may be necessary for the voltage of the dynamo to be considerably higher than that required by the lamps. One plan is to have two separate switches connected to the reserve cells, as shown in Fig. 26, the charging current from the dynamo being led in through one, and the current for the lamps passing out through the other, so that the potential can be independently controlled in the two circuits. Another method is to insert counter-E. M. F. cells (without active material) in the circuit between the dynamo and the lamps, in order to bring down the voltage of the former to suit the latter. The number of these cells is varied in accordance with the excess of the potential of the dynamo.

Simple resistance coils may be used in place of the counter-E. M. F. cells to reduce the pressure; but the cells have the great advantage, that they have an effect practically independent of variations in the current. All these methods, however, involve a waste of power, the value of which in watts is the product of the current in amperes and the number of volts by which the potential is cut down. In small plants this loss is not serious, but in large plants or central stations it may become very considerable.

Booster Methods of Regulation. The best plan is to make use of a *booster,* in which case the main dynamos are run at the proper voltage to supply the lamps directly, and the additional pressure required to charge the battery is furnished by the booster. This is connected in series with the dynamo, being inserted in the circuit between the latter and the battery.

When a battery is placed at the end of a long feeder to compensate for line drop, and at light loads to act as a storage reservoir, it is not usual to equip this *floating battery* with any regulating device. In such cases the battery is simply connected across the line, and the charge and discharge are determined by the feeder drop. For instance, when a small load is on the line, the drop is small, and the potential applied across the battery terminals is high enough to send a charging current into the battery; if the load on the line increases, the drop naturally increases, the pressure at the end of the line falls, and, if it falls below the battery voltage, the battery discharges in parallel with the generator, carrying a certain portion of the load. The floating battery has the advantages of simplicity, and acts immediately, as it has no time lag, which is always present in any apparatus depending upon changes in magnetization. Usually the variations in voltage and the fluctuations in load are too great for successful operation of a floating battery on any but an electric railway or power circuit, and a booster is required if incandescent lighting is a part of the load.

The duty of a booster is to vary the voltage at the battery terminals with variation in load, causing charging or discharging of current as conditions may require. The booster is an auxiliary dynamo, the E. M. F. of which is used to raise or lower the voltage in the battery circuit. These machines are classified as *series, shunt, compound, differential,* and *constant-current* boosters.

Shunt Booster. This is a shunt dynamo, driven by any source of power, having its armature circuit in series with the line from generator to battery. This form is used in plants where the battery is not designed to take up load fluctuations, but is in service only to carry the peak of the load, being charged during periods of light load, and discharged in parallel with the generator. It acts to increase the voltage applied to the battery so that the charg-

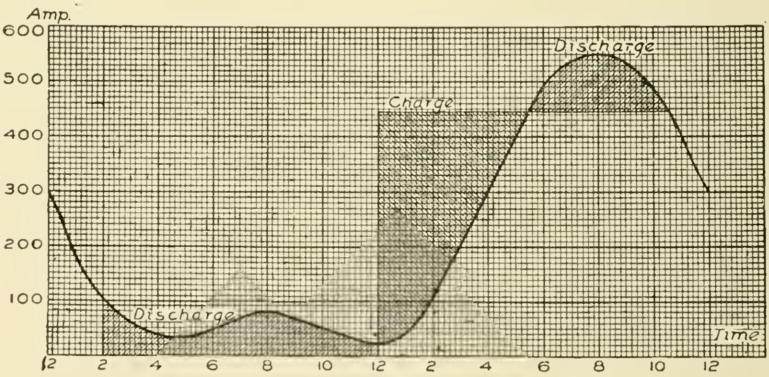


Fig. 29. Load Diagram of Case in which a Shunt Booster is Applicable.

ing current will flow into the latter. As a rule, the battery used in conjunction with a shunt booster is made large enough to carry the entire load during the light-load period. As the battery discharges and its voltage drops, the end-cells (regulation cells) are cut in and the proper voltage maintained. Fig. 29 shows a load diagram to which this system is applicable, and Fig. 30 shows diagrammatically the connections of this system. The booster (7) is direct-connected to and driven by a shunt-covered motor (8), which takes current from the main bus-bars. The field of the booster is provided with a single winding excited from the generator circuit. This winding has a rheostat (10) in series with it so as to be able to regulate to booster E. M. F. It is to be noted that the shunt booster is not applicable where there are sudden fluctuations which are great compared with the capacity of the generator, and that it is not automatic in changing from charge to discharge, the switching being performed by hand.

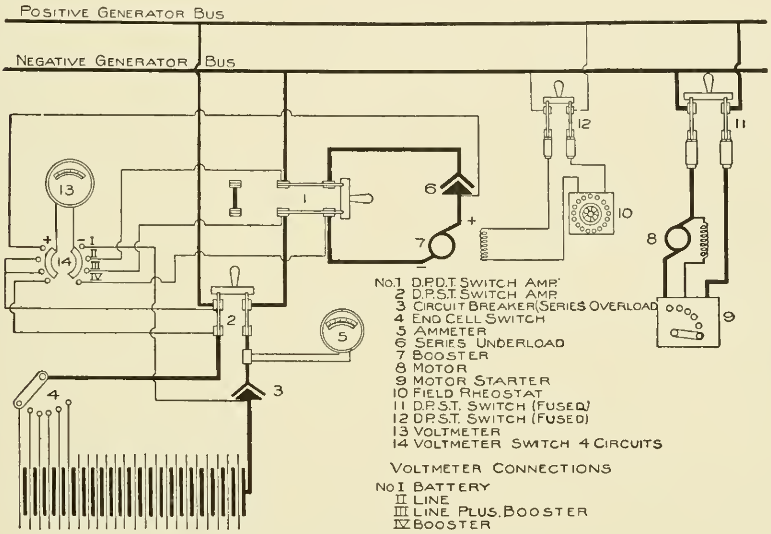


Fig. 30. Shunt Booster Connections.

Series Booster. The connections are like those of the shunt booster with the battery and booster in series across the line; but the field of booster being in series with the battery circuit, its E. M. F. is zero when no current is flowing in or out of the battery. Should the voltage of the line rise, due to a decrease of load, and a charging current flow into the battery, the E. M. F. of the booster would increase, and thus tend to increase the rate of charge. The reverse occurs when the battery discharges, as an increase of load on the line increases the current through the series field of the booster, thus raising the voltage of discharge so that the battery carries a larger part of the load.

This booster acts to compound the battery on discharge, and tends to maintain a constant voltage on the line. It depends on the fact that the generator voltage falls when the load increases; hence it is used with a shunt generator or equivalent source of supply.

This system is applicable to power, but not to lighting purposes, and is similar in its operation to a floating battery. It is not so extensively used as the compound and differential booster arrangements, which give better regulation under similar conditions.

Compound Booster. This system is used on railway and power circuits with great fluctuations in load, the battery action to prevent excessive drop and to assist the generating machinery in carrying the load, relieving it from the strain of sudden rushes of current. The connections of this system are indicated in Fig. 31, and the operation is as follows: Under normal load conditions the shunt field F_h of the booster creates an E. M. F. in the same direction as the battery, tending to discharge it. Calling E_g the generator E. M. F.; E_a the booster E. M. F.; and E_b the battery E. M. F., we have $E_g+E_a=E_b$ when no current is flowing into or out of the battery. In this case the generator carries the whole external load.

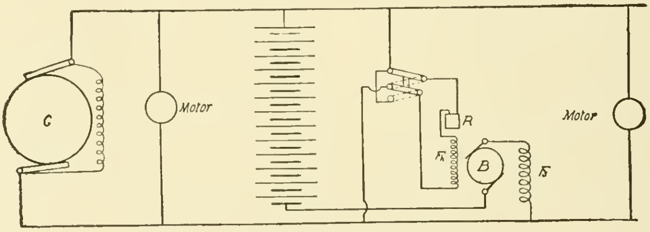


Fig. 31. Compound Booster Connections.

If the load increases, E_g decreases, so that E_b-E_a is greater than E_g, and the battery begins to discharge. In discharging, the current passes through the series field F_s of the booster and produces a proportional E. M. F., acting with the shunt field to raise E_a, thus increasing the battery discharge and shifting more of the load from the generator, until the system becomes balanced.

If the load on the external circuit be light, the generator voltage E_g rises and current flows into the battery. In this case the series field acts against the shunt field and decreases E_a, so that the generator voltage is greater than booster and battery voltage combined, thus increasing the rate of charge of the battery, until the load causes the generator voltage to drop to normal and the system is again balanced. The battery and booster can be placed at the power house or at the point at which the greatest drop is likely to occur.

A battery can also be used to help out the generators at the peak of the load, by increasing the shunt-field current and thus causing $E_a + E_b$ to be greater than E_g.

Since this system also depends for its action upon the drop of voltage with increase of load, it is only applicable to shunt-wound generators or equivalent source.

Differential Boosters. The differential booster system most commonly used is shown in Fig. 32. The compensating field S_1 prevents the variation of the battery E. M. F. from disturbing the equilibrium of the system. If the battery E. M. F. be lower than normal, it will not discharge rapidly enough to relieve the generator from overload fluctuations, unless the booster E. M. F. be increased; and the generator will therefore have to supply a current of greater than its normal value. If, however, a current of greater value than the normal flows through S_1, the value of $f - S_1$ is decreased, and S_2 still further overpowers the resultant of $f - S_1$ and causes a higher booster E. M. F., tending to discharge the battery, thus bringing down the generator load to normal. Should the battery E. M. F. be above its normal value, the battery would discharge too rapidly and carry

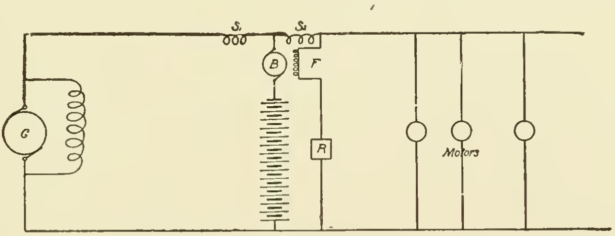


Fig. 32. Differential Booster Connections.

more than its share of the load; in this case f–S_1 is greater than it should be, and the booster E. M. F. causes the load to become evenly distributed between the battery and generator.

In operating this system, the varying load must be beyond the booster equipment. If desired, the coils S_1 and S_2 may be short-circuited so that the battery may be charged more rapidly.

Constant-Current Booster. In systems having short lines and small drop, it is often desirable to have the voltage fall on sudden application of an overload, so that the rush of excessive current is prevented. This rush of current occurs in buildings where elevator and power motors constitute a large percentage of the load; and to prevent it, the *constant-current booster* system is used.

Fig. 33 represents a constant-current booster system, in which the main current passes through the armature and series field of the booster; and this current does not reverse.

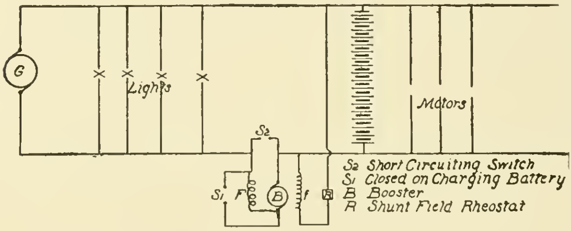

G
Lights
Motors
S_2
S_1
F
B
f
R
S_2 Short Circuiting Switch
S_1 Closed on Charging Battery
B Booster
R Shunt Field Rheostat

Fig. 33. Constant-Current Booster Connections.

The voltage impressed on a fluctuating load of motors, on the right, is greater than that impressed on a non-fluctuating load of lamps on the left, by the amount of the booster voltage.

The shunt-coil f creates an E. M. F. in the same direction as that of the generator; while the series-coil F opposes it.

Should a load come in the motor portion of the circuit, the generator sends a greater current through the series coil F, the action of which reduces the booster E. M. F. in direct proportion to this rush of current, and causes the booster E. M. F. to vary inversely as the motor load, thus tending to maintain an almost constant current delivery from generator. If it is desired to have the battery furnish power to both lights and motors, at periods of light load, and not to use the generator, this can be done by simply opening the generator switch and short-circuiting the booster by closing switch S_2.

The switch S_1 is closed in charging the battery, as the rate of charge can be controlled by varying the shunt-field resistance R.

This is often done, when the battery has been carrying a heavy load for some time and the recharging must be hurried.

In the automatic booster systems already described, the regulation is obtained by two or more field windings acting differentially or cumulatively.

Systems of External Control. In the following systems of booster control, only a single field winding is provided, and this winding is excited from the main bus-bars through an automatic field regulator which varies the field current to produce the necessary booster E.M.F. as the load on the line changes. The booster armature is connected in series with the battery and generator as heretofore. Figs. 34 and 35 show diagrammatically the connections of the differential and constant-current systems arranged on this plan.

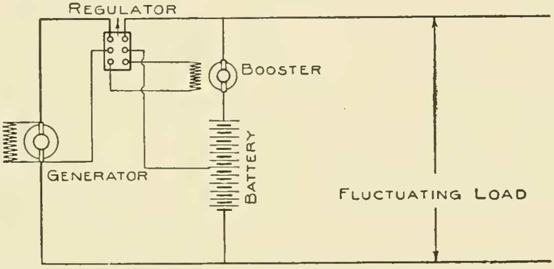


Fig. 34. External Control Differential Booster System.

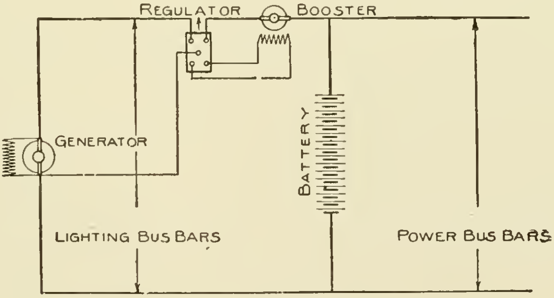


Fig. 35. External Control Constant-Current System.

These externally controlled booster equipments are the system employed by the General Storage Battery Company, and in one of these constant-current systems the following excellent regulation was obtained: The load across the power bus-bars was a rapidly fluctuating one, varying instantly from zero to 2500 amperes, while the average current required amounted to only 150 amperes. With no load across the power bus-bars, the booster passed 150 amperes from the generator to the battery, tending to charge the latter; with a sudden increase of power demands from zero to 2500 amperes, the generator current rose to a value of only 159 amperes. This example brings out the definition of a constant-current booster, that is, it should be one which maintains a practically constant power load on the generator.

EDISON LOW VOLTAGE STORAGE CELLS*

Brief reference to the Edison storage battery has already been made on page 18, but the unique features of this type of cell and the wonderful increase in the number of small storage battery installations in late years make it desirable to treat the construction of the nickel-iron cell more at length. Its development is an example of the successful outcome of a long series of experiments extending over a number of years. The chief virtue of the cell is its ability to stand up under heavy duty and abuse.

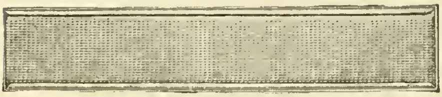


Fig. 36. Edison Negative Element

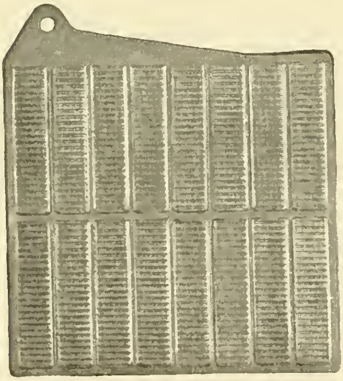


Fig. 37. Complete Negative Plate
Courtesy of Edison Storage Battery Company

Special Features. *Electrolyte.* All other storage batteries contain an electrolyte which attacks the plates. Edison uses a solution of potash which does not attack the plates but really preserves them. Therefore, the battery can be left standing in a charged or uncharged condition for an indefinite period without losing its good properties. The specific gravity of this electrolyte does not change with charge or discharge of the cell so that the taking of readings is avoided.

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*The remainder of this article was written by John P. Schroeter, Consulting Electrical Engineer, American School of Correspondence.

Plates. The plates do not consist of lead, as in the ordinary storage battery, but of nickel, iron oxide, and steel. For the negative plate, iron oxide is pressed into steel pockets, Fig. 36, and a number of these pockets are mounted on a steel grid or support, Fig. 37. For the formation of the positive plate, nickel hydrate (a green powder) is put into perforated steel tubes, Fig. 38, and these tubes are mounted together on another steel grid, Fig. 39.

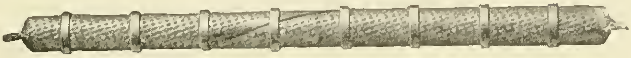


Fig. 38. Edison Positive Tube Containing Nickel Hydrate

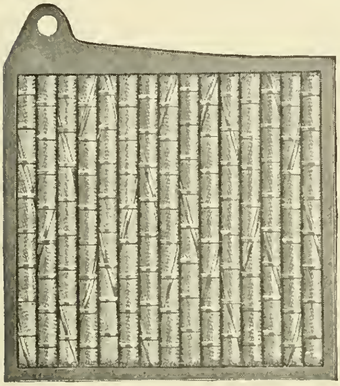


Fig. 39. Complete Positive Plate
Courtesy of Edison Storage Battery Company

Assembling. In an assembled cell, Fig. 40, it is of course necessary to keep the plates from touching each other and this is accomplished by putting hard rubber rods between them in the crevices formed between adjoining tubes of the positive plates. The container into which the assembled plates are placed is a pressed steel can, all seams of which have been welded by the oxygen-acetylene blowpipe. For mechanical strength and greater radiating surface, these cans are corrugated. The top of the cell, shown in Fig. 41, is also welded to the can, and openings are provided for the electrical connections and for pouring in the solution. The latter opening has a cap containing a little valve which allows the generated gases to escape when the cell is being charged, but prevents any impurities from getting inside. Fig. 42 shows the manner in which four cells are arranged in a tray for convenience in handling.

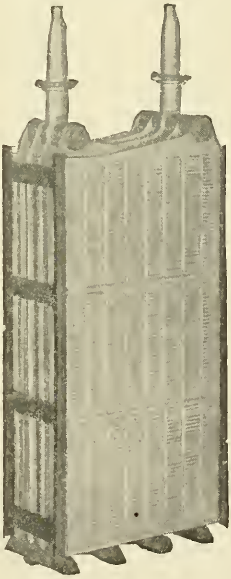


Fig. 40. Edison Cell Completely Assembled

Charging and Discharging. The charging current, in flowing through the solution from the positive to the negative plate, causes the oxygen of the iron oxide to come over to the nickel hydrate and oxidize it, forming a new kind of nickel oxide.

The initial charge is given in the factory so that the cells are ready for work on arriving at their destination. The cells may be discharged for short periods at any rate desired but they should discharge for ordinary loads, at about 25 per cent in excess of the normal charging rate. The amount of recharging depends entirely upon the amount of the previous discharge. A "boosting" charge at from two to five times the normal rate may be allowed for limited periods.

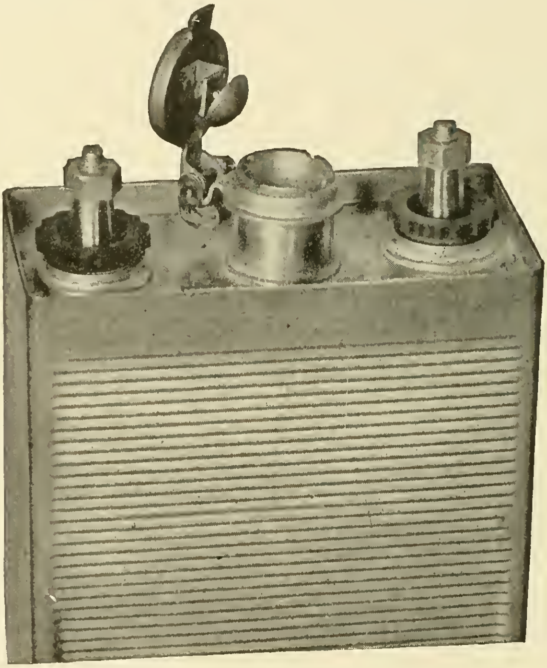


Fig. 41. Pressed Steel Container Showing Cap with Safety Valve
Courtesy of Edison Storage Battery Company

Claimed Advantages. *No Fumes Given Off.* There are no poisonous gases given off on account of the absence of any acid. This avoids the danger of metal parts becoming so corroded as to impair or interrupt the electrical contact.

Ability to Stand Abuse. Special attention in the manufacture has been paid to the item of rough handling and abuse, and the tests made before this battery was placed on the market were of the severest kind. Very little attention is necessary for its proper working. It is a rigid unit that can be destroyed or damaged by sheer force only. It is practically not affected by temperature changes, as tests have shown that it works as well below zero as above 100 degrees.

No Penalties for Non-Use or Inattention. An overcharge is necessary only every two months after it has been brought to its proper working strength. It can be discharged to zero, short circuited, left standing without any attention for six months, and will not show any appreciable bad effects.

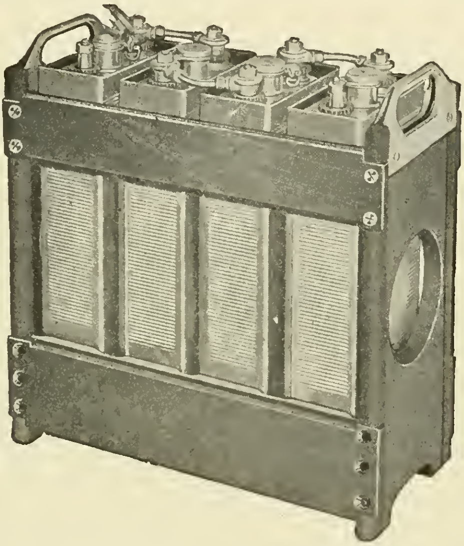


Fig. 42. Four Edison Cells Mounted Conveniently for Handling
Courtesy of Edison Storage Battery Company

Long Life. Its life can not yet be determined, as it has not been long enough on the market, but very severe laboratory tests have shown it to be apparently indestructible under usual working conditions.

Light Weight. Its light weight is one of the chief advantages. As a comparison it may be shown that a 16-cell lead battery of the car-lighting type, giving 32 volts, weighs 2880 pounds, while a 25-cell Edison battery of the same voltage and capacity weighs only 800 pounds, a saving in weight of 2080 pounds.

Types of Cells. Edison batteries are manufactured in various capacities and sizes, all of which have plates of the same thickness and width, the variations being only in height and number of plates. Fig. 43 shows a row of the different types, those designated *B* having plates one-half the size of the *A* types. The number following the letter indicates how many positive plates are used, the number of negatives always exceeding the positives by one. Each of the *A* types is also made in a special high form with the same sized plates but with a somewhat higher can, in order to give a larger space for the electrolyte.

Output and Efficiency. The output of an Edison cell is determined by the capacity of the positive electrode. The cells have not as high a capacity when new as after some weeks of use, the increase continuing for twenty or even more complete charges and discharges. The output and efficiency depend upon three factors: the rate of charge, the amount of charge, and the rate of discharge. Fig. 44 shows the relation of current output to current input when charges of different lengths are given to a cell at $\frac{2}{3}$, 1, and $1\frac{1}{3}$ times normal rate. It may be noticed that the normal input (210 ampere-hours for an *A*-4 cell) comes very close to the sharpest point of the bend. Fig. 45 gives the characteristic curves showing the output and efficiency for this normal input point. It will be noticed that the voltage per cell is only about 1.25 volts during the greater part of the discharge, being nearly 1.5 volts at the beginning and one volt at the end.

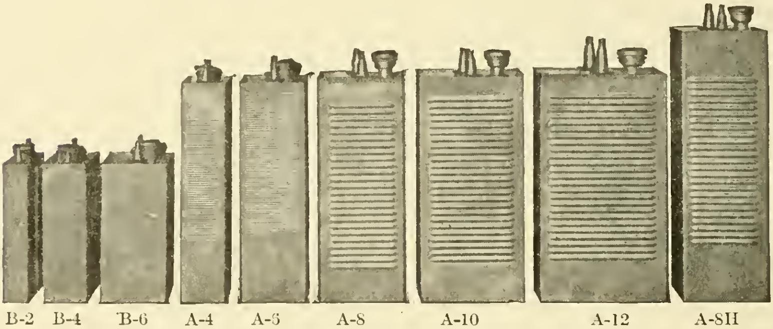


Fig. 43. Row of Edison Batteries Showing Various Types
Courtesy of Edison Storage Battery Company

Specific Output. In making comparisons of storage batteries of different kinds, one important item is the output in relation to weight

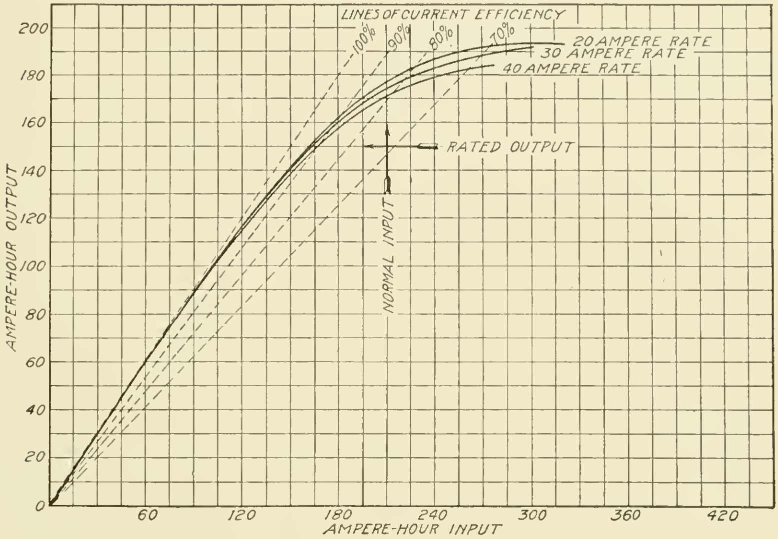


Fig. 44. Curve Showing Ratio of Current Output to Current Input in an Edison Cell
Courtesy of Edison Storage Battery Company

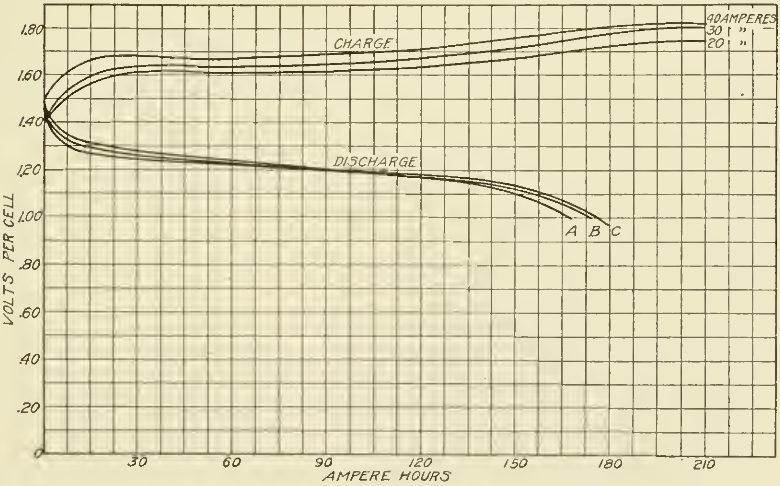


Fig. 45. Curve Showing Variation of Voltage on Charge and Discharge in an Edison Cell

and volume. It is obvious that this point must be considered for all non-stationary installations. The volume may not be of such importance if it is within reasonable limits, but the weight will decidedly influence the economy when the battery is applied to any moving vehicle. Fig. 46 gives the energy output at different rates of power delivery calculated for one pound of Edison battery. The same referred to one cubic foot is shown in Fig. 47. The figures are based on the total weight and maximum volume of a complete battery of a standard number of cells.

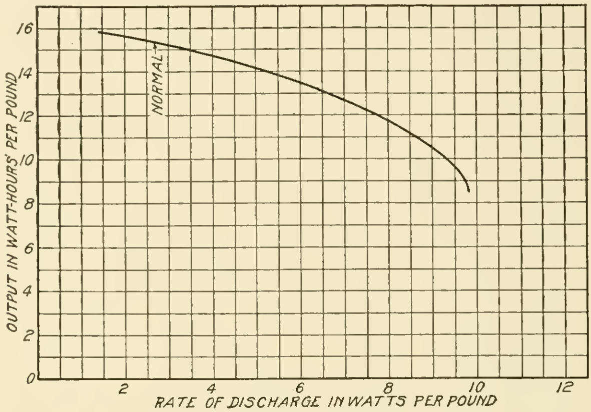


Fig. 46. Energy Output at Different Rates per Pound of Battery
Courtesy of Edison Storage Battery Company

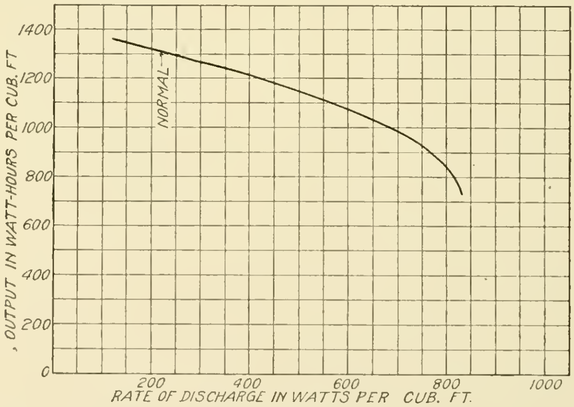


Fig. 47. Energy Output at Different Rates per Cubic Foot of Space Occupied
Courtesy of Edison Storage Battery Company

Effects of Temperature. The statement has been made that the Edison battery is not affected by temperature changes, but this does not mean that there will not be a certain temperature at which it works to its best advantage. As regards immediate output, it has been found that charging cool, say, at a cell temperature of 75° to 85° F., and discharging hot, say, at a cell temperature of 120° to 130° F. is the most advantageous. The output will be low, if charging is done at a cell temperature below 50° F. or more than 105° F. The same is true if the battery is discharged at too low a temperature. The latter disadvantage is compensated for, however, by the fact that the temperature of the cell is to a great degree influenced by its resistance, the temperature rising as the resistance increases. A low outside temperature, therefore, will increase the resistance of the cell and, consequently, the temperature within the cell will be raised, thus providing a kind of automatic regulation. The same regulation, only in the reverse sense, is true in case of high temperature within the cell.

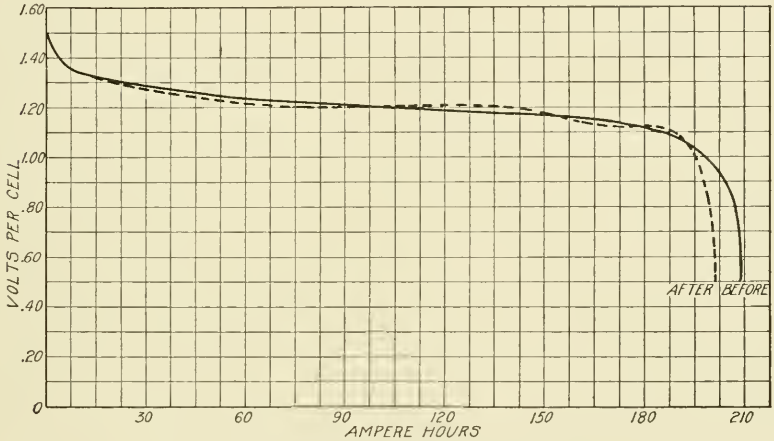


Fig. 48. Curve Showing Effect of Charging Cell in Wrong Direction for Fifteen Hours
Courtesy of Edison Storage Battery Company

Endurance of Abuse. The Edison battery may be considered practically "fool proof", which of course does not mean that it should not be handled with all possible care. The manufacturers have carefully considered this item and many tests show how they have succeeded. Fig. 48 illustrates that no injury resulted when a discharged cell was connected up in the reverse direction and charged at the normal rate for 15 hours. Contrary to what would be expected, it has even been found that no immediate harm will result if the battery is left without electrolyte. It is obvious that this statement must not be construed to mean that there would be no harm whatever if such treatment were continued for any length of time.

SMALL STORAGE BATTERY INSTALLATIONS

The storage battery in small capacity units has been used in enormous quantities in recent years for lighting automobiles and railway cars, for furnishing auxiliary current in isolated lighting plants, and in many other ways too numerous to mention. A brief description of the best methods already developed will be given in order that some idea of the scope of these applications may be gained.

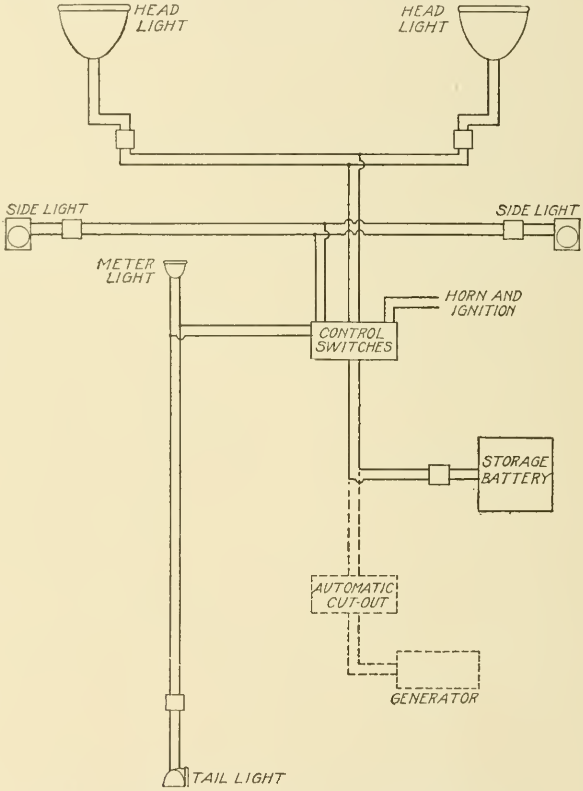
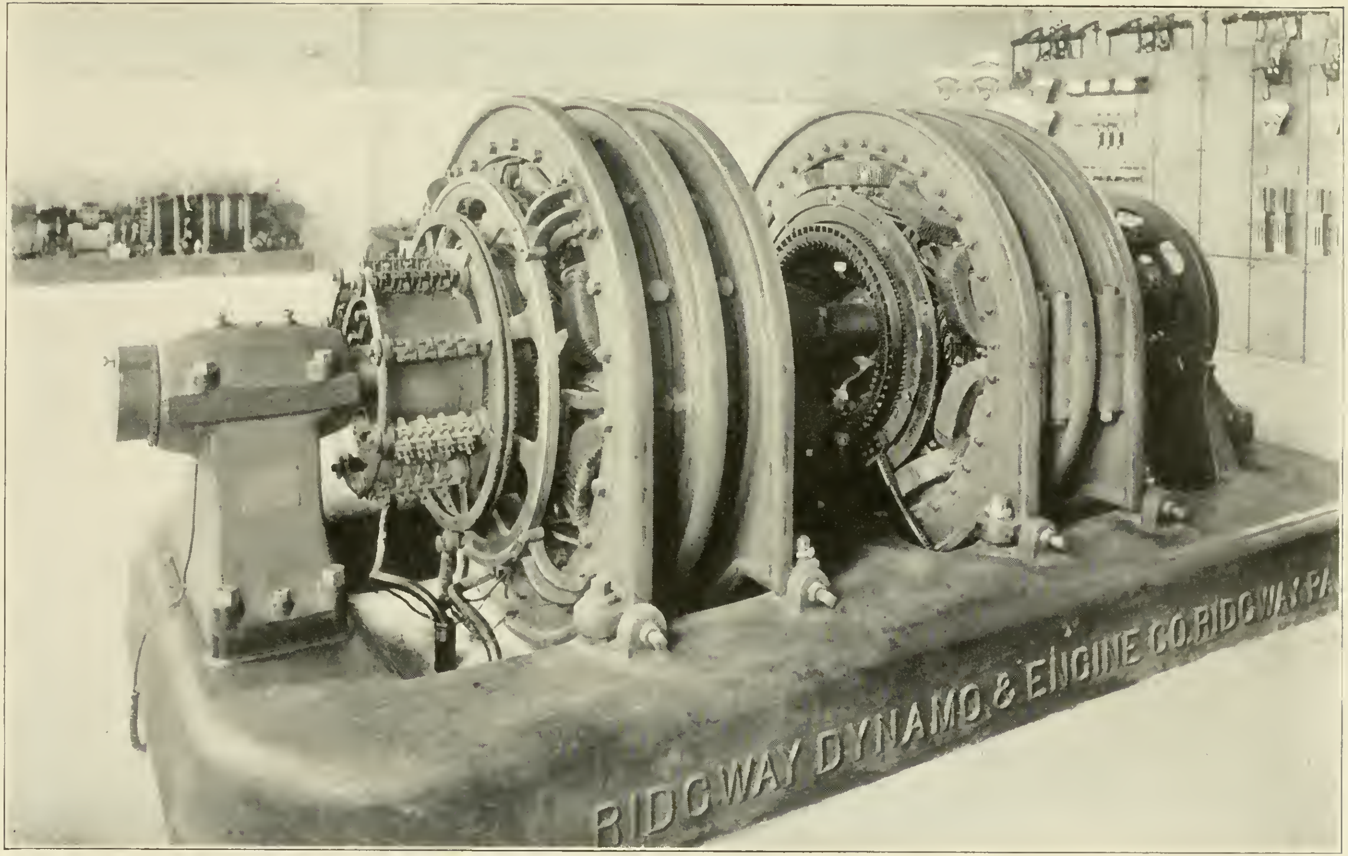


Fig. 49. Wiring Diagram for Automobile Lighting Equipment
Courtesy of Gould Storage Battery Company

Automobile Lighting. It seems unnecessary to justify the use of an electric lighting system for automobiles, as the simple operation



BOOSTER SET FOR DETROIT RIVER TUNNEL PLANT

Courtesy of Gould Storage Battery Company

of throwing a switch in order to obtain the necessary light is so much easier than stopping the car and stepping out into the rain or mud tc "light up" an oil or acetylene system. But there are other advantages besides convenience, such as reliability, cleanliness, and simplicity. No ventilation of the lights is necessary, which makes it possible to keep them entirely closed, thus insuring a clear light at all times. There are two kinds of automobile lighting, depending exclusively or partially on the use of storage batteries.

Straight Storage Battery System. The straight storage battery system, as the name implies, depends entirely upon storage batteries; lamps of suitable voltage and power with the necessary switches, wiring, sockets, etc., are provided. The Gould Storage Battery Company furnishes special 6-volt sets having 50 to 150 ampere-hours capacity. This system works very well in city service, where searchlights are seldom used. Garages rent such batteries and exchange them when discharged for fully charged ones.

Generator System. Where it is intended to use the lamps for exceptionally long intervals, as in country driving, which would also necessitate the constant use of searchlights, a small generator is used in connection with a storage battery, while at high speeds the generator feeds the lamps and at the same time delivers its surplus into the battery. When the car is running during the day, the entire power of the generator is delivered to the battery. The battery gives out its power at slow speeds, and when the car is at rest, the whole system works automatically. Fig. 49 gives a diagram of wiring for a straight battery, or generator, system. The sizes of wire recommended are: from battery and generator to control switches No. 10; searchlight circuit No. 10; side-light circuit No. 12; and tail and meter light circuit No. 14.

Railway Car Lighting. There are numerous advantages of lighting railway cars by electricity, some of which, of course, apply to any electric light installation. However, one great factor to add in car lighting is the impossibility of fire as the result of an accident. At such times gas tanks have the bad habit of exploding, allowing the gas to catch fire and igniting the wrecks. Many people have lost their lives, not directly by the derailment of the train, but by the fire which started in the gas tanks. This point alone should be of sufficient weight to compel all railroads to abandon the obsolete gas-lighting systems now that it has been found possible to create an electric system which is in all respects superior. There are several systems by which illumination by electricity may be effected, but as we are concerned with storage batteries, we will consider only those systems which take into account their application.

It is quite clear that we could employ storage batteries without an auxiliary generator, but there are some disadvantages in such a plan, one of which is that it is necessary to charge the battery from an outside source. By the same token, a system would be possible which involved the exclusive use of a generator. There is such a system, in which the electricity is generated by means of a special turbine, placed on the locomotive and receiving the steam directly from the boiler. The combination of generator and storage battery, however, seems the best solution.

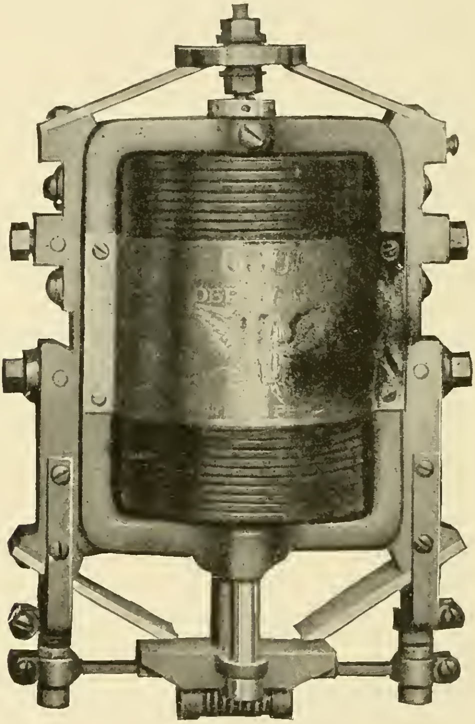


Fig. 50. Automatic Switch for Cutting Generator In and Out in Axle-Lighting System
Courtesy of Gould Coupler Company

Gould Simplex Axle-Lighting System. One of the best systems of this kind is called the Gould Simplex System, in which the generator is mounted on the car axle. This gives each car a power plant, independent of the road on which it is running or of the terminal facilities.

The first essential to the success of such a system is that the voltage of the lamps be kept constant, regardless of the direction of rotation of the axles of the car and consequently of the generator, and regardless of the variable speed of the train. This requires that the generator field strength should vary inversely with the speed. The storage battery is a very important part of this equipment, because light must be furnished when the car is at a standstill or moving very slowly. The essential features of the Simplex system are: the axle-driven generator; a mechanical pole changer for the reversal of the armature circuit in accordance with the direction of the train movement; an automatic regulator for the control of the generator field; an automatically operated switch for cutting the generator out or in; a voltage regulator for the lamp circuit; and the storage battery. The generator, mechanical pole changer, and automatic regulator do not concern us, but the automatic switch and voltage regulator which are used in connection with the storage battery will be described. Fig. 50 shows such an automatic switch which is of the laminated copper contact type with auxiliary carbon break. It is closed against the action of gravity by the lifting of a solenoid core. The solenoid contains two windings: one a shunt coil across the generator, the other a series coil carrying the generator current. As soon as the generator voltage reaches a definite value, the shunt coil becomes of sufficient strength to raise the plunger and close the switch. Current then begins to flow through the series coil and holds the switch tightly closed. If the speed decreases so that the generator cannot hold its voltage, the battery tends to discharge through the series coil in the opposite direction, thus neutralizing the pull of the solenoid and allowing the force of gravity, reinforced by the spring, to open the switch and break the generator circuit.

The voltage of the generating system is that of the storage battery and as soon as the battery approaches the condition of being fully charged, the voltage will be so high as to soon burn out the lamps. In order to insure constant brilliancy of the lamps, an

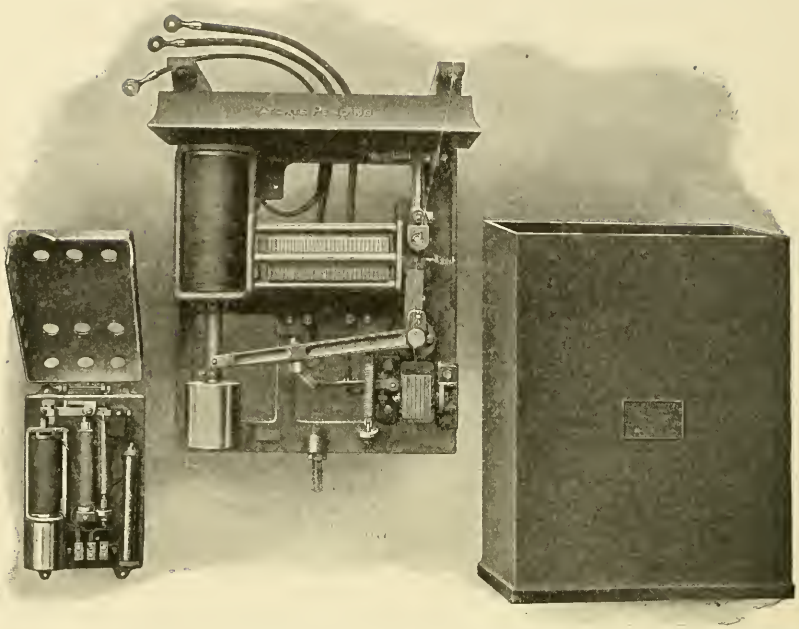


Fig. 51. Automatic Voltage Regulator for Control of Generator Field in Gould Simplex System
Courtesy of Gould Coupler Company

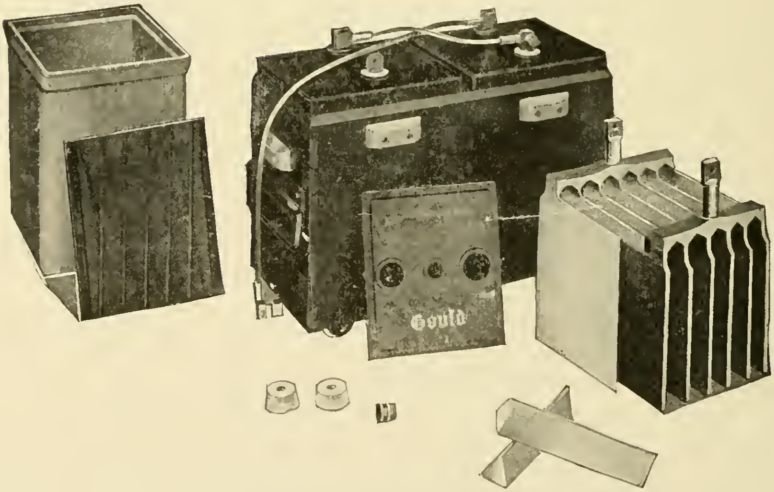
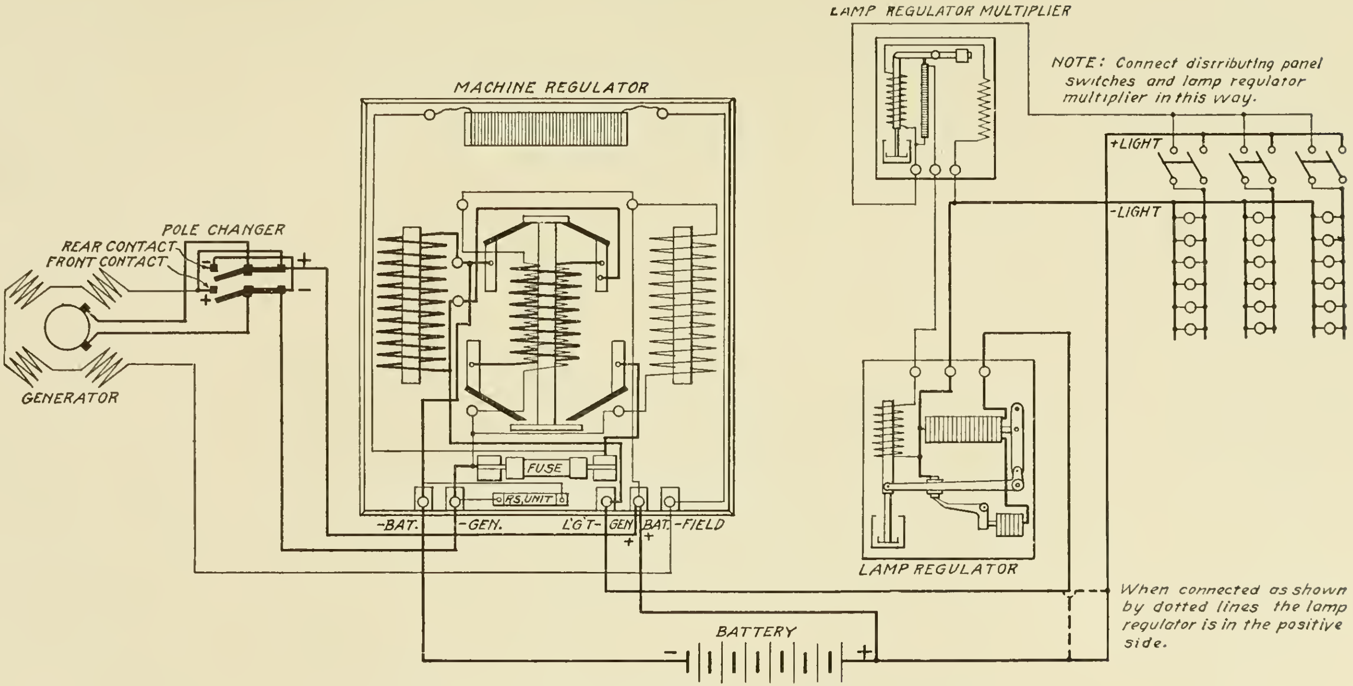


Fig. 52. Partially Dismounted Gould Two-Cell Car-Lighting Unit
Courtesy of Gould Coupler Company



NOTE: Connect distributing panel switches and lamp regulator multiplier in this way.

When connected as shown by dotted lines the lamp regulator is in the positive side.

Fig. 53. Wiring Diagram for Gould Simplex Axle Lighting System
Courtesy of Gould Coupler Company

automatic voltage regulator, Fig. 51, is inserted in the lamp circuit. This device comprises a resistance, consisting of a series of carbon plates the pressure upon which is made to vary inversely with the voltage of the generating system. A solenoid plunger acting on a lever arm exerts this variable pressure, the current in the solenoid being controlled by an auxiliary regulator, also of the carbon type, acting as a multiplier. By this means a very slight increase in the voltage will result in a decided increase in lifting effort on the main

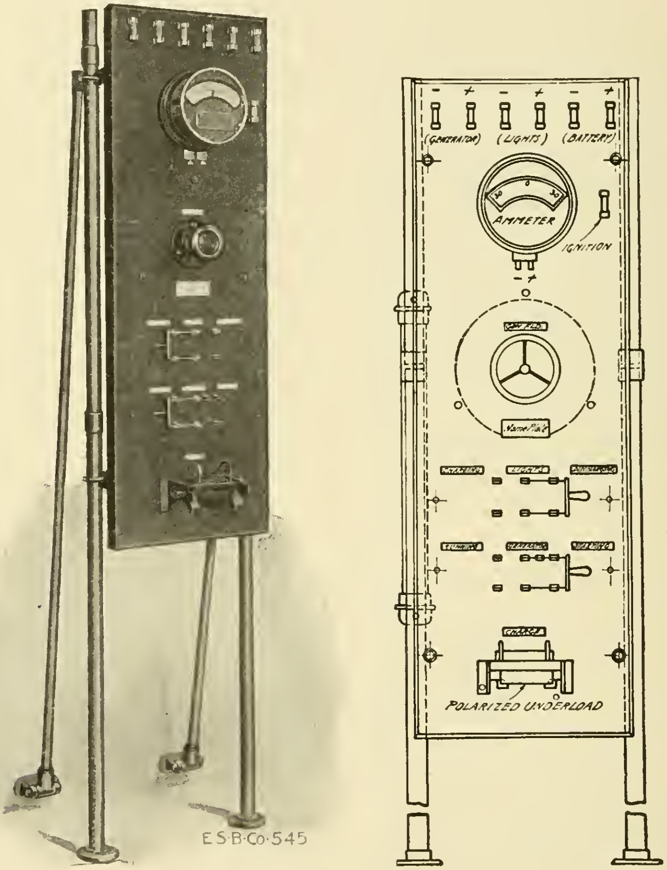


Fig. 54. Switchboard for a House-Lighting Outfit
Courtesy of Electric Storage Battery Company

plunger so that the lamp voltage and candlepower are maintained at approximately the same value.

Fig. 52 shows a Gould 2-cell car-lighting unit and Fig. 53 gives a wiring diagram for the necessary circuits.

House Lighting. In the days of the old carbon-filament incandescent lamp, their low efficiency made the small isolated lighting plant a very expensive proposition. When the tungsten lamp was introduced with an efficiency nearly three times as great, the current consumption was cut down to such a point that a low voltage installation became extremely economical. As a result, where central power is not available, small 32-volt installations are highly recommended. The low voltage has the further advantage of being entirely safe; no shocks need be feared and only 16 cells of the lead type are necessary. These isolated plants consist generally of a prime mover—now mostly a gas engine; a dynamo; a switchboard; a storage battery; and the necessary appliances such as switches, fuses, meter, etc. It is obviously important in small plants that the generator need not run continuously. If we consider, for example, such an installation on a farm, the gas engine and the generator are

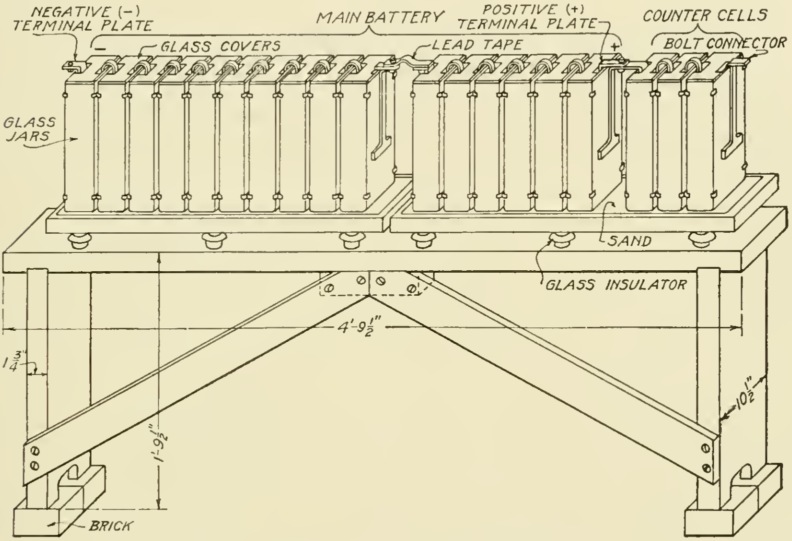


Fig. 55. House-Lighting Battery Mounted on Bench
Courtesy of Electric Storage Battery Company

working for several hours in the daytime, but at night it would hardly be economical to run the generator for a few lights only. The storage battery fills the gap here and furnishes all the needed light by simply throwing a switch.

Details of an Installation. The Electric Storage Battery Company furnishes for its installations two different switchboards, each of which permits certain combinations in the management of the plant. One of these consists of the following instruments: an ammeter to read the amount of current flowing when the battery is either charging or discharging (charging current is read to the left of the zero point, discharging to the right); a field rheostat for adjusting the voltage of the generator; a polarized underload circuit breaker, which will allow the circuit to open in case of trouble with

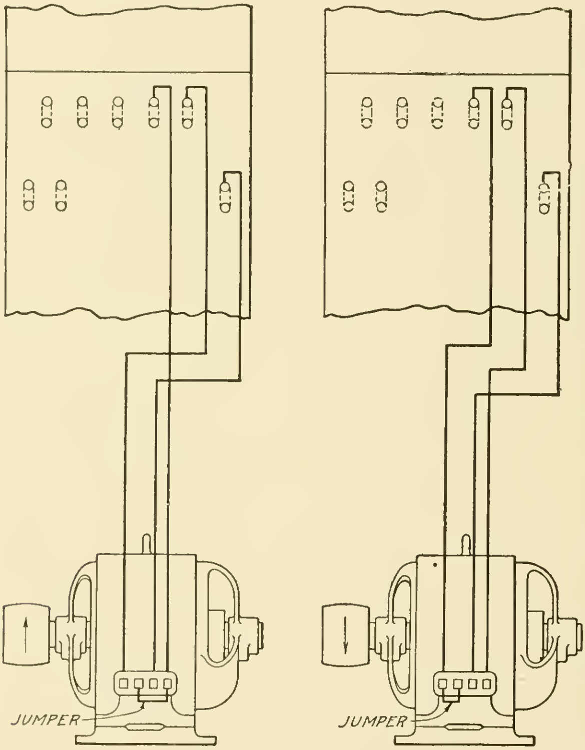


Fig. 56. Wiring Diagram from Dynamo to Switchboard for Clockwise and Anticlockwise Rotation

the gas engine while charging; two double-pole double-throw switches; fuses, etc. Fig. 54 shows such a switchboard. The following combinations are possible with it: to charge the battery alone without using lights; to charge the battery and furnish current for a few lamps; to light lamps from battery; to light lamps by both generator and battery; and to light the lamps by the generator alone in case this should be necessary.

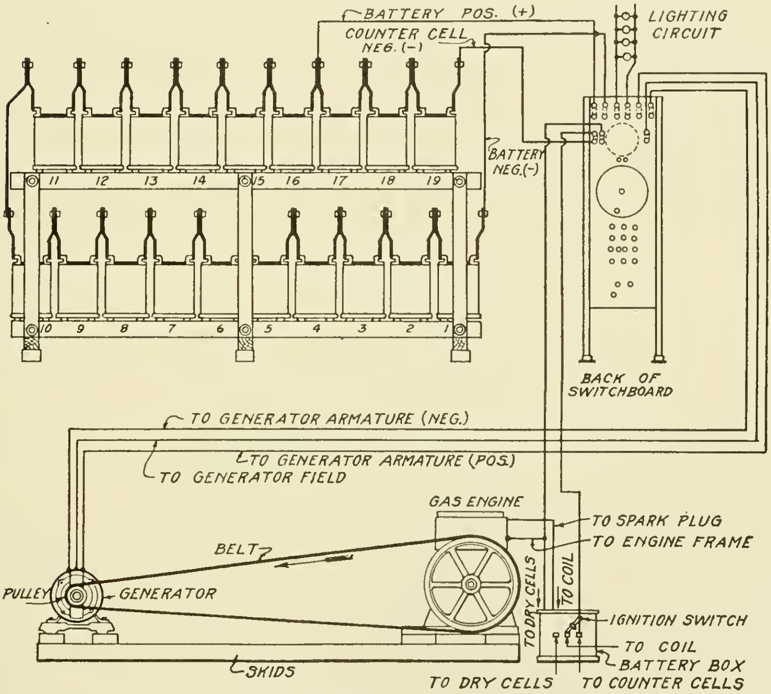
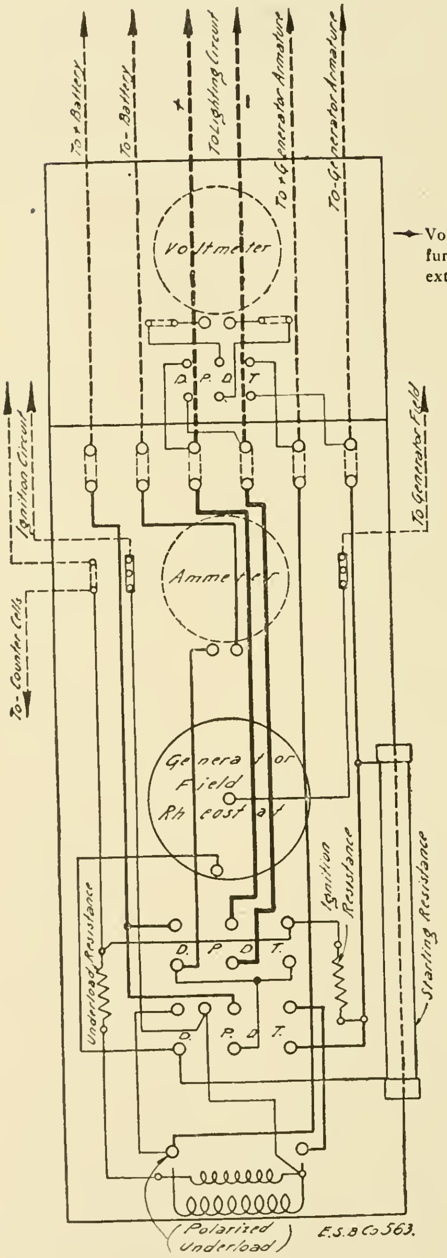


Fig. 57 Complete Wiring Diagram of House-Lighting Installation
Courtesy of Electric Storage Battery Company

Fig. 55 shows a battery mounted on a bench, with a few counter cells provided for the better regulation of the voltage. Fig. 56 illustrates the standard connections between dynamo and switchboard for clockwise and anticlockwise rotation. Fig. 57 gives the diagram of a complete installation, the connections for the back of the switchboard being given in Fig. 58.

The other outfit is simpler, consisting of pilot lamp, ammeter, rheostat, polarized underload circuit breaker, a double-pole throw



Voltmeter Panel furnished as an extra, if ordered

Fig. 58. Back of Switchboard Shown in Fig. 57
Courtesy of Electric Storage Battery Company

switch and fuses. Fig. 59 shows the switchboard arrangement. The only combinations possible with it are: to charge the battery and to light the lamps from the battery alone. A diagram of the connections for the complete plant is given in Fig. 60.

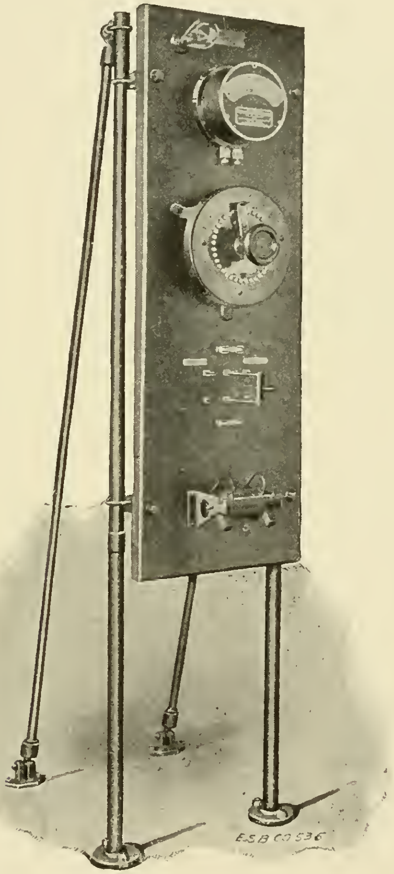


Fig. 59. Simple House-Lighting Switchboard
Courtesy of Electric Storage Battery Company

Notwithstanding the usefulness of these plants, they have the disadvantage that they are not very well fitted for power purposes. This is not the fault of the battery but rather of the manufacturers who have not yet fully standardized low voltage motors. In case power is essential, a high voltage plant is usually installed, that is, one giving 110 volts; in this case the cost for the battery is much higher, but otherwise, from a technical standpoint, the installation is the same.

Ignition Service. When storage batteries are used in connection with gas engines, it is always possible to take the current for the ignition system from the batteries. If we refer to Fig. 49, it will be noticed that a connection has been provided for the ignition circuit. The battery being always well charged will give as much trouble as an independent battery system. We will find further in

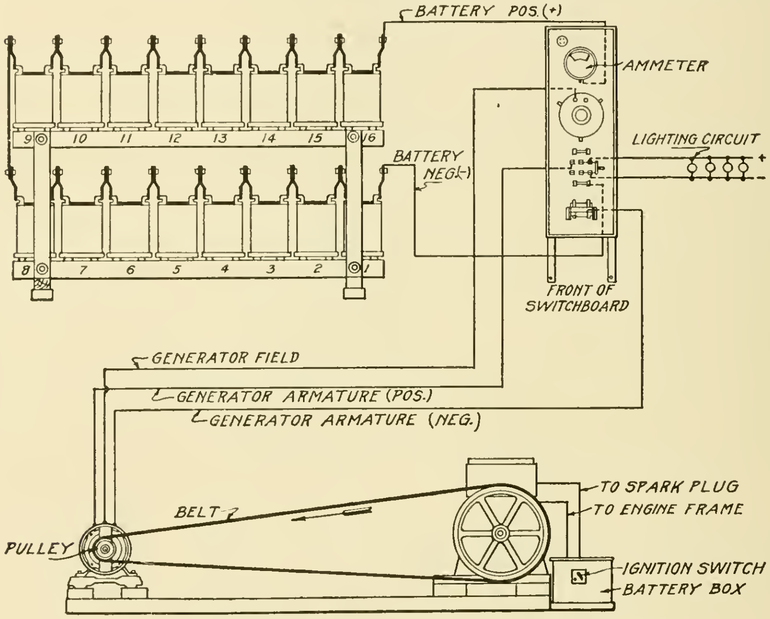


Fig. 60. Complete Wiring Diagram for Simple House-Lighting Installation
Courtesy of Electric Storage Battery Company

Figs. 57 and 58 connections to the igniter in isolated plants. It is customary to provide a reserve sparking battery so that if one becomes completely discharged or meets with an accident, a second is available. Fig. 61 shows such a battery arranged in a portable box. (See Fig. 62 for plan of top.) For those who wish to have a reserve sparking battery, a smaller unit is manufactured called the emergency battery. When occasion requires, this battery may be switched into circuit, thus allowing the motor to be operated while the main battery is being recharged or repaired. Another arrangement for stationary gas engines consists of two storage batteries, one of which is being charged while the other one is operating. Where charging current is available at the point where the batteries are used, connections similar to those shown in Fig. 63 may be made. *A* represents the source of charging current, and *B* the bank of lamps which are used as resistance, *C* and *D* are two double-pole double-throw switches connected at their hinges to the two batteries *E* and *F*. *G* represents the leads to the sparking coil terminals. It will readily be seen from the diagram that by throwing the switches in opposite directions, one battery will be charging while the other one is discharging to the engine, thus giving a constant source of supply, at the same time insuring that the spare battery will be ready for service as soon as the other one is discharged.

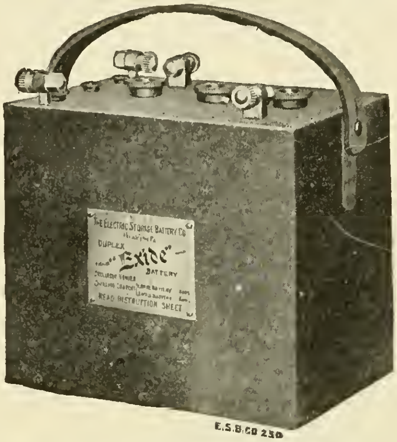


Fig. 61. Small Ignition Battery with Double Circuit
Courtesy of Electric Storage Battery Company

Electric Vehicles. The usefulness of an electric vehicle depends largely upon the storage battery, because it furnishes the propelling power to the motors. It is not the intention to go into the construction and management of electric automobiles and trucks, however, as it hardly comes within the scope of this article. The underlying principles are very simple. A storage battery of sufficient capacity drives the motors of the vehicle and at the same time furnishes current for the lights. The great simplicity in handling

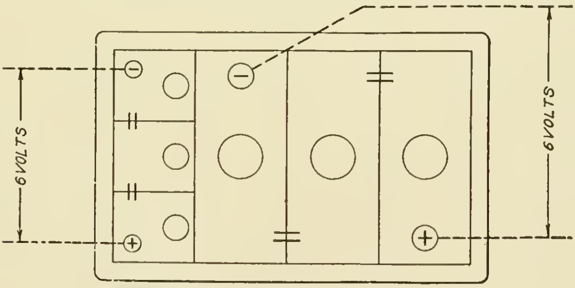


Fig. 62. Plan of Duplex Battery Shown in Fig. 61

such vehicles makes them a favorite for ladies. On account of their small radius of action, they are practically limited to city use. It is clear that the weight of the battery is one of the greatest items to be considered, and the exertions of the manufacturers and scientists have been mostly directed towards lessening the weight factor. Another point to be considered is their ability to withstand sudden jars, vibrations, and rough usage. What Edison did in these respects has already been mentioned.

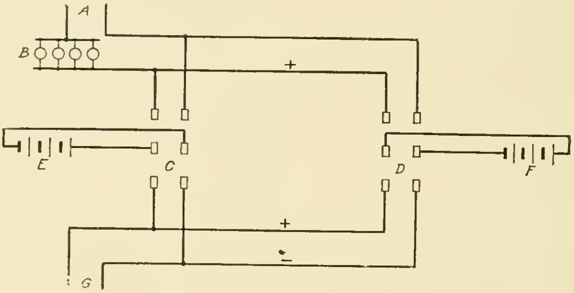


Fig. 63. Wiring Diagram for Ignition Battery Charging Circuit

Ironclad Exide Cells. In the Ironclad Exide battery, which is manufactured by the Electric Storage Company, the positive plate consists of a grid composed of a number of parallel vertical metal rods, united to horizontal top and bottom frames, the former being provided with the usual conducting lug. Each vertical rod forms a core which is surrounded by a cylindrical pencil of peroxide of lead—the active material. This in turn is enclosed in a hard rubber tube provided with a large number of horizontal slits which allow the electrolyte, or solution, to reach the active material. Fig. 64, which shows a vertical section of a single pencil, makes this construction clear. Each tube is provided with two parallel vertical ribs which project on opposite sides and stiffen the plates, acting also as insulating spacers. Fig. 65 shows a side view of one tube. The rubber tubes have a certain amount of

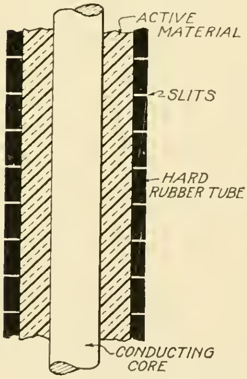


Fig. 64. Section of Exide Positive Tube

elasticity, thus allowing for changes in volume of the active material. Fig. 66 shows a complete positive plate. The negative plate is the standard Exide type. The advantages claimed for this battery are: high voltage; high efficiency; low internal resistance, and consequent ability to discharge at very high energy rates—a valuable attribute for hill climbing and bad roads; marked recuperative power; greatly increased life; very infrequent necessity for cleaning.

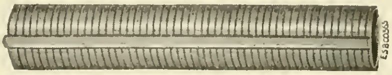


Fig. 65. Side View of Positive Tube
Courtesy of Electric Storage Battery Company

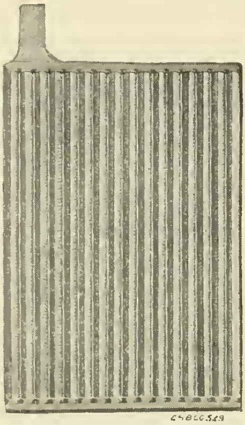


Fig. 66. Exide Positive Plate
Courtesy of Electric Storage Battery Company

Charging Process. One of the most important operations is the charging of the exhausted batteries and it will not be out of place to give the general instructions as issued by the Gould Storage Battery Company. The diagram in Fig. 67 shows the general method of charging. The trays are first connected in series and the positive terminal of the supply line connected to the positive pole of the first tray. The negative terminal is connected to the negative pole of the last tray, so that the current will flow through all the cells. The voltmeter is so

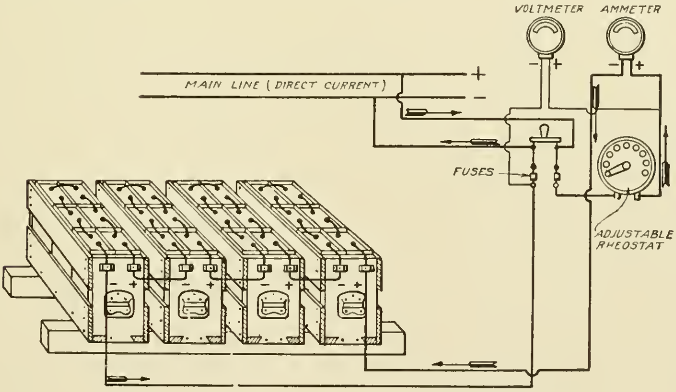


Fig. 67. Wiring Diagram for Charging a Bank of Storage Cells
Courtesy of Gould Storage Battery Company

connected that it will show the battery voltage only. The line voltage should be at least 2.65 times the number of cells in the battery. The rheostat is for the regulation of the voltage, but if such device is not at hand a water rheostat will do the work. This water resistance may be easily constructed as follows: Take a small wood tub filled with clean water. Suspend from movable wood sticks resting on top of the tub, two sheet lead plates.

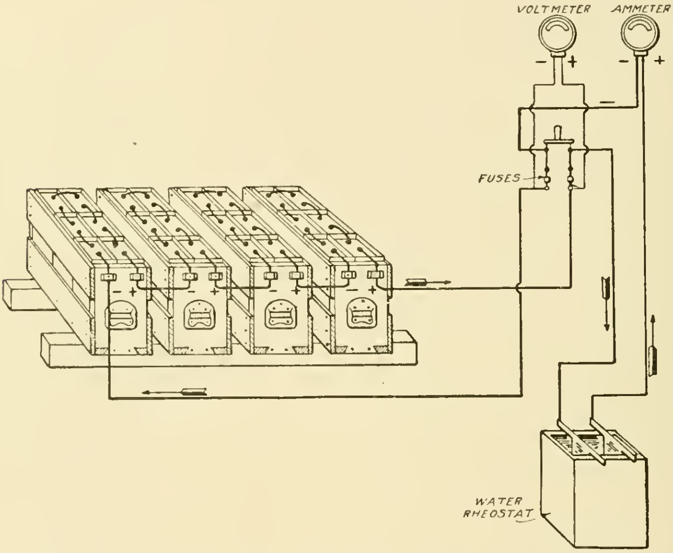
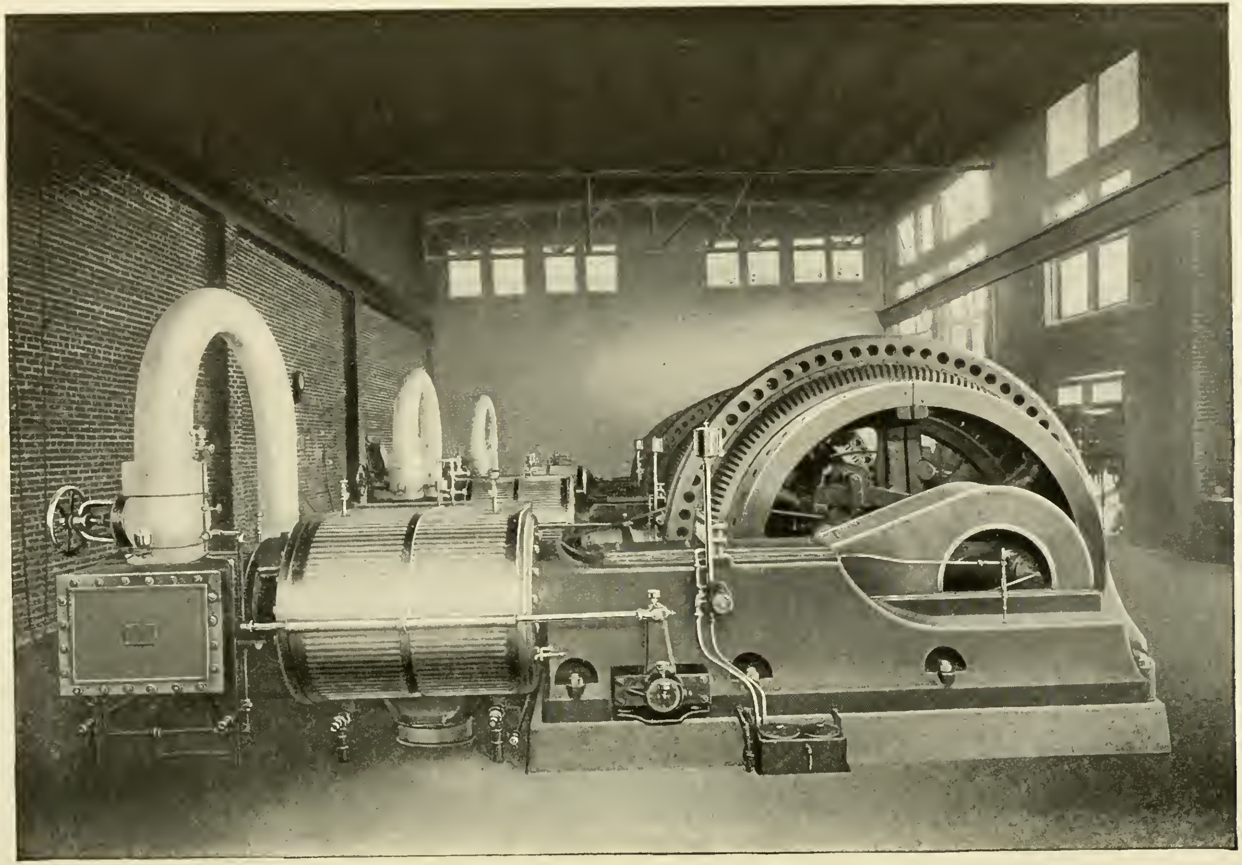


Fig. 68. Wiring Diagram for Charging Circuit Containing Water Resistance
Courtesy of Gould Storage Battery Company

Bring wire from the battery through one side of the switch to one of the plates in the water resistance, running from the other plate to an ammeter, through the other side of the switch, and to the opposite pole of the battery. When the switch is closed, the flow of the current may be regulated by moving the lead plates nearer or farther apart. Moving the plates apart increases the resistance and, therefore, decreases the current; while moving them together or adding a little electrolyte decreases the resistance and, therefore, increases the current. Fig. 68 illustrates the arrangement of such water resistance.

Electric Launches. The electric launch is the ideal pleasure craft. She is noiseless, odorless, and simple to control; there is



INSTALLATION OF SKINNER ENGINES OPERATING ALTERNATING-CURRENT GENERATORS

Courtesy of Skinner Engine Company

one rotating part only; the start can be quickly made; and a minimum of attention is sufficient. Special attention has been paid to the development of the Edison battery for this type of service and it has several distinct advantages over other kinds. One of these is that it is not necessary to dismount the battery for the winter, as must be done with the lead battery. Another advantage is the absence of corroding fumes, thus excluding all danger of an attack on the metal parts of the boat. There are no special features in the connections of storage battery and motor.

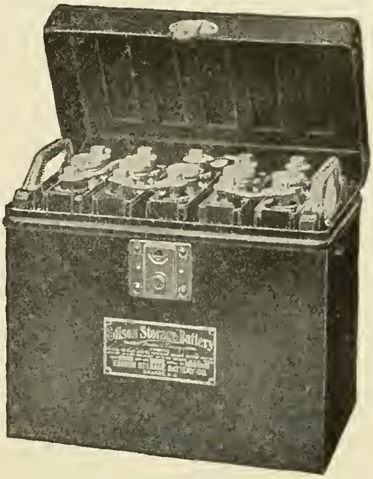


Fig. 69. Edison Storage Battery Unit for Signal Work
Courtesy of Edison Storage Battery Company

Special Applications. We are mostly concerned with very small capacities and it is convenient to have the batteries in a portable form. Fig. 69 illustrates five cells

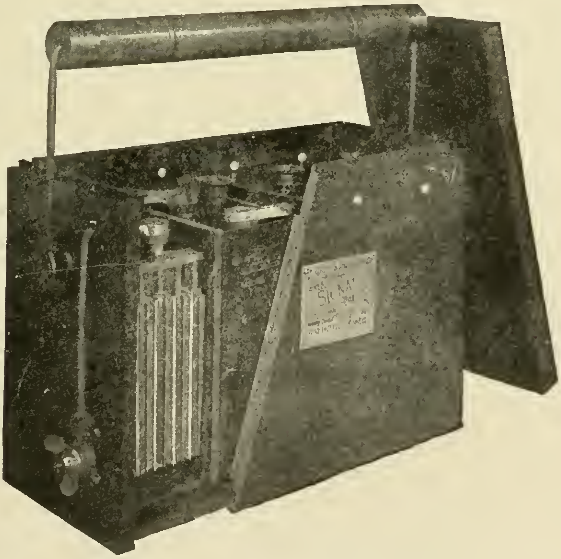


Fig. 70. Part-Section of Exide Signal Cells
Courtesy of Electric Storage Battery Company

of the Edison type, arranged in a steel box. These small units are useful for surgical appliances, dentist's outfits, laboratory uses, etc. Fig. 70 shows a group of Electric Storage Battery signal cells assembled in a case. They are extensively used in railway signal service.

Other applications which may be mentioned are for self-starters and electric horns—both great conveniences for automobilists; portable batteries for work in telephony, wireless telegraphy, etc.

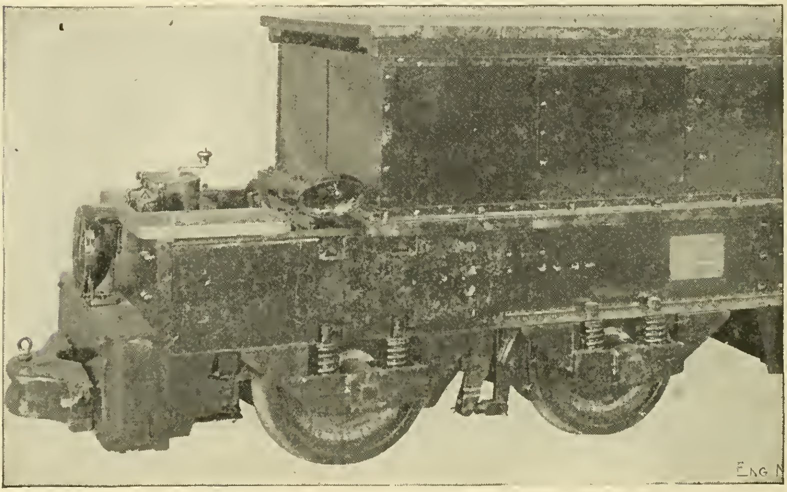


Fig. 71. Electric Mine Hauling Locomotive
Courtesy of Engineering News

A larger field is still open in which experiments have just begun, that is, the use of storage batteries for traction purposes. It is clear that in tunnels and mines especially, storage batteries should be used. The absence of any fumes and of any danger due to the overhead construction of electric conductors or the third rail is avoided. Fig. 71 illustrates a mine hauling locomotive. Such locomotives are used for hauling cars of excavated material to the mouth of the shafts in one of the sections of the Catskill water-supply distribution tunnels under New York. The batteries are of the lead type, comprise 44 cells, and have a five-hour discharge capacity. The cells are grouped in four or more trays and mounted on the top of the locomotive frame in a sheet iron case. Each locomotive has an ampere-hour meter, a headlight, and a gong. Further trials and experiments are in progress and it may be said that we are just beginning to realize the great possibilities of the storage battery.

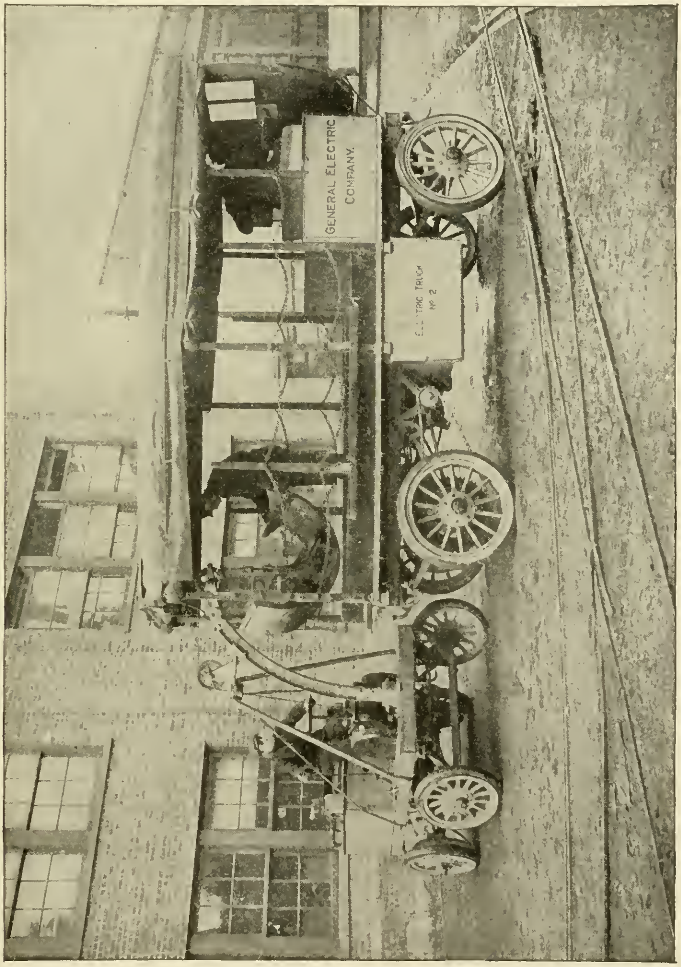


Fig. 72. Battery Truck Loading an Electric Dray
Courtesy of General Electric Company

A battery truck loading an electric dray is illustrated in Fig. 72.

Charging Outfits. One of the drawbacks to the extensive adoption of storage batteries has been the expense and inconvenience of sending the battery out at regular intervals for recharging when no house circuit was available, or the necessity of providing expensive and delicate instruments in case only alternating current was available. This objection has been removed by the invention of small alternating-current rectifiers, by means of which an alternating-current circuit may be used. In the Edison rectifier are no rotating parts or vacuum tubes and the method of operation is as simple as the turning off and on of a switch. Fig. 73 is a wiring diagram for the outfit which includes a regulating rheostat and an ammeter to provide correct adjustment. Fig. 74 shows another type of charging rectifier, manufactured by the Westinghouse Company. It is especially designed for charging three-cell lead storage batteries. This apparatus consists essentially of a polarized relay upon which two alternating-current magnets act, thus causing it to vibrate in synchronism with the alternations of the current. It is so arranged that it reverses the connection of the circuit as the current reverses. The two stationary magnets are of the same polarity at each instant and, therefore, if the alternating current is in one direction, we have north poles attracting the south end of a vibrating arm and repelling the north end. This connects the alternating-current in one direction to the direct-current circuit. When the alternating current reverses, the magnets become south poles attracting the north end of the vibrating arm and repelling

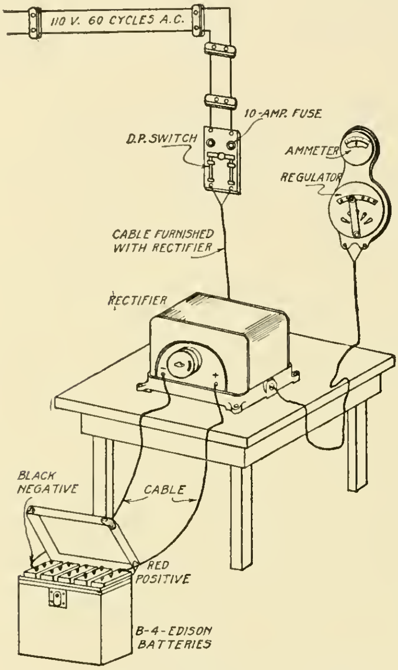


Fig. 73. Wiring Diagram for Using Edison Rectifier

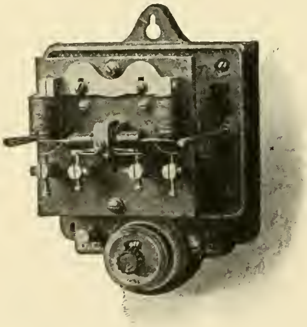


Fig. 74. Westinghouse Rectifier with Cover Removed

the south end. This reverses the connection of the alternating-current to the direct-current circuit, but as the direction of the current has also reversed, the current flows in the same direction as before. This rectifier can be operated on any 60-cycle circuit of 100 to 120 volts and will charge at a rate of 6 to 8 amperes.

Where a direct-current circuit is available, the connections may be made according to Fig. 75, which shows as a rheostat a bank of lamps inserted into the circuit. The lamps are used for the regulation of the current. It should be remembered that a 16 c. p. lamp will carry one-half ampere and a 32 c. p. lamp, one ampere; their resistance being 220 and 110 ohms, respectively. Therefore, if we want a current of six amperes, we will have to connect into the circuit either twelve 16 c. p. lamps or six 32 c. p. lamps. The lamps to be used must be of the carbon-filament type, because the tungsten lamps have different characteristics. The ammeter shown in the figure is not essential. Instead of lamps, we may connect a rheostat in the circuit, as shown in Fig. 76, or any other suitable resistance. If we assume that for the charging of a lead cell two volts per cell are necessary, the resistance to be inserted into the circuit can be calculated according to the formula

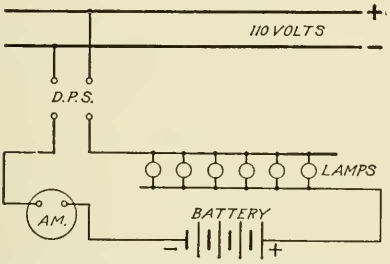


Fig. 75. Wiring Diagram for Charging Batteries from Direct-Current Circuit Using Lamps as Resistance

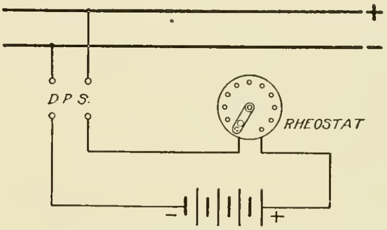
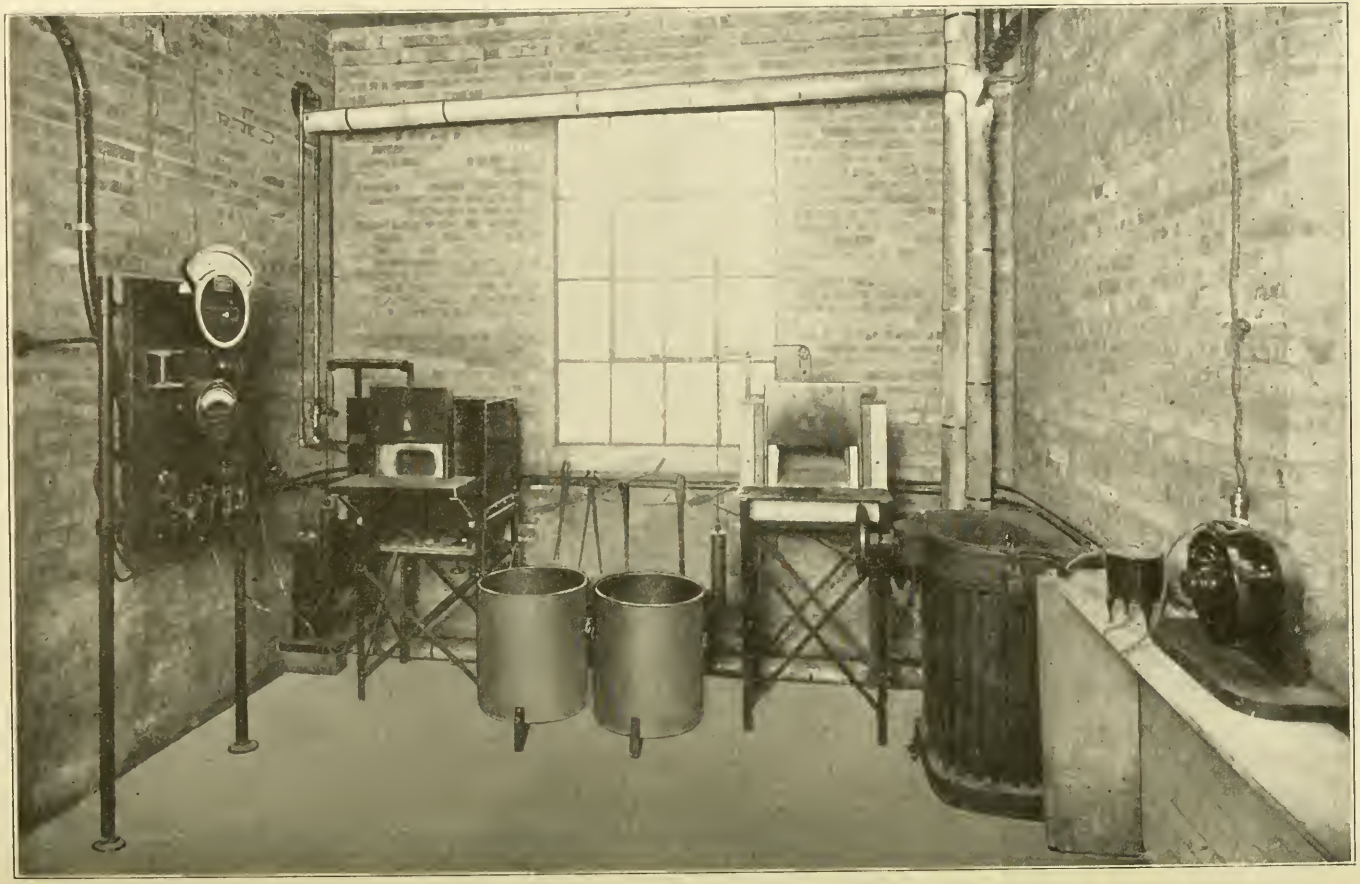


Fig. 76. Charging Diagram Using Rheostat as Resistance

$$r=\frac{e-2n}{i}$$

where r denotes the resistance, e the voltage of the supply circuit, n the number of cells to be charged, and i the charging current.



INSTALLATION OF HOSKINS ELECTRIC FURNACES FOR TOOL HARDENING

Courtesy of Hoskins Manufacturing Company

APPLIED ELECTROCHEMISTRY

INTRODUCTION

Chemical Reactions. Chemical reactions are frequently, if not in fact almost universally, associated with changes in electrical energy. The science and art of electrochemistry deal with the relationship of electrical and chemical forms of energy. It is well known that many chemical reactions take place with the liberation of energy in the form of heat; thus when coal burns, combining with the oxygen of the air, there is a liberation of heat energy. Certain other chemical changes involve an absorption of heat energy, that is, heat must be applied to materials in order to cause certain reactions to take place. The formation of calcium carbide is an example of the production of a useful compound by heating lime and carbon to a high temperature. All chemical reactions may be classified as either *endothermic*—heat-absorbing reactions—or as *exothermic*—heat-liberating reactions.

Numerous chemical transformations also occur with a liberation of electrical energy, a fact upon which are dependent the various types of primary cells or electric batteries. Electrical energy may, on the other hand, be made to produce chemical changes by the passage of electric current through an electrolyte, and this finds practical application in various forms of electrolytic cells.

Storage batteries constitute an important class of electrical apparatus, consisting of a certain combination of metals and electrolyte in which the electrochemical action is reversible, that is, in passing current through the battery in one direction certain chemical changes take place, or the battery is stored or charged, and these chemical reactions take place in a reverse direction when the current is allowed to flow in a reverse direction, as when the battery is discharged.

Range of the Subject. The fundamental units and principles of electricity, the elementary principles of electrochemical action, the primary cell, and the secondary, or storage, cell have already been considered in previous articles, and consequently this article will be confined to a consideration of the wider field of applied electrochemistry, dealing with the more important practical uses of electrical energy in producing useful chemical transformations.

Electrical energy may be applied to materials by various methods, the more important of which are the following:

(1) Electrolysis, or the electrolytic change brought about by the passage of a direct current through an electrolyte.

(2) Electrothermics, or the production of chemical change through the heat effect produced by electrical means.

(3) Electrical discharge in gases.

ELECTROLYSIS AND ITS APPLICATIONS

ELECTROCHEMICAL THEORY

KINDS OF CONDUCTORS

All materials may be divided, first, into two classes, depending upon whether or not they conduct electrical current. If they conduct, they are called "conductors" and if they do not, they are designated as "insulators". In turn, materials which conduct may again be subdivided into two more classes commonly designated: *metallic conductors,* or *conductors of the first class;* and *electrolytic conductors,* or *conductors of the second class.*

It is important that as a basis for the study of electrolysis a clear idea be acquired as to the distinctive differences between metallic and electrolytic conductors.

Metallic Conductors. As implied by the name, *metallic conductors,* the metals belong to this class; and in addition to the metals and metallic alloys, there are a few other elements and various compounds which conduct in a similar manner and are therefore designated as metallic conductors. In this class of conductors the flow of current produces only a heating effect without producing chemical change.

Non-Metallic Elements. Of the few non-metallic elements which conduct, the most important is carbon, or graphite. Silicon, boron, and selenium are other elements possessing metallic conductivity to some degree.

Chemical compounds do not as a rule conduct metallically. The important exceptions include peroxide of lead, which is a constituent of one of the electrodes in a storage battery; magnetic oxide of iron, Fe_3O_4, which is used as an anode material for electrolytic purposes; sulphides of lead and of silver, various metallic carbides, silicides, borides, etc.

Specific Resistance. The specific resistances of the metals and metal alloys cover a comparatively limited range, a high resistance metal such as mercury having a specific resistance about one hundred times that of the best conductive metals, copper and silver.

It is a characteristic of the metals that the resistance varies in a minor degree with variations in temperature. The resistance usually increases with increase in temperature, or, in other words, the metals have a positive temperature coefficient. With pure metals the temperature coefficient is a constant, i. e., the resistance is approximately proportional to the absolute temperature and, if the resistance be plotted for various temperatures, the line points toward absolute zero, suggesting that if the metals could be cooled to that point they would possess no resistance and thus become perfect conductors.

With the conductive metalloids or non-metals, and with the compounds which conduct metallically, a higher order of specific resistance is encountered as well as a greater variation in temperature coefficient. To the electrochemist, carbon is the most important of these conductors. Its specific resistance varies through a wide range from that of the diamond, which is practically an insulator, to graphite, and then to "metallized" carbon which has a conductivity comparable to that of mercury.

Carbon, such as is used for electrode purposes, may consist of plates made up of finely ground carbon mixed with a binding material, molded into shape and subjected to a high temperature baking. The resistance is dependent upon the quality of the carbon flour, the purity, the nature of the binding material, the pressure of forming, and the baking temperature. The higher the firing temperature used, the lower is the resistance and, by carrying the temperature to the highest attainable value, the material is transformed into a more conductive form known as graphite. The discovery of this method of graphitization by electric heating constitutes one of the most important of the electrochemical discoveries, furnishing not only the basis of a large artificial graphite industry but also supplying an electrode material of inestimable value to the electrochemist.

By data taken from various sources it appears that the commercial forms of electrode carbons have values of specific resistance varying from 3000 to 10,000 microhms per $\overline{\text{cm}}^3$. Graphitized electrodes have a specific resistance of about 800 microhms and the value for metallized carbon has been given as 480 microhms.

The so-called metallic silicon has a specific resistance which varies greatly and in an uncertain manner with increase in temperature. Boron is a conductive material which has only recently been produced but which has created special interest, in that it has a temperature coefficient which is higher than almost any other known substance. A small rod of this material, which shows a resistance of over 5,000,000 ohms at 27° C., shows 46,000 ohms at 180°. The conductivity of selenium likewise possesses interesting characteristics. This element has a high specific resistance, it has a high temperature coefficient and possesses the unusual feature that it changes its resistance notably under the influence of light.

The chemical compounds which conduct metallically are characterized by a high specific resistance and a high negative temperature coefficient.

Electrolytic Conductors. *Characteristics.* The most important characteristic of electrolytic conductivity is that the flow of current produces a chemical transformation. The detection of a chemical change does not, however, constitute an infallible means of determining whether a material should be placed in this class, since under certain conditions the resultant chemical change may be so slight as to avoid detection. Faraday concluded that certain fused chlorides, for example, conducted metallically, because he could detect no appreciable decomposition. The conclusion was probably erroneous, due to the fact that the products which were liberated immediately reunited to form the original substance.

Electrolytic conductors invariably consist of definite chemical compounds. It should be borne in mind that, as pointed out under metallic conductors, not all chemical compounds which conduct are electrolytic conductors.

Classification. Electrolytic conductors may be either fused materials or certain solutions of materials in water or other solvents. Some evidence of electrolytic conductivity has been detected in a few solid compounds, but this phenomenon is of little importance from the practical standpoint. It is with liquid conductors that electrolysis commercially applied has to deal and for practical purposes these liquid conductors may be placed in three divisions:

(1) Electrolytes consisting of substances dissolved in water.
(2) Electrolytes consisting of substances dissolved in solvents other than water.
(3) Electrolytes consisting of chemical compounds in a state of fusion.

The first group is the one of the greatest importance, since water is a great universal solvent, which, on account of its abundance and low cost and great solvent properties, furnishes an essential material in most industrial electrolytic processes. Non-aqueous solutions, while attracting much interest from the theoretical and scientific points of view, have as yet few technical applications. A more extensive use of these solvents, however, may safely be anticipated as a result of future development.

Electrolytes consisting of fused materials have important technical applications in industries such as the manufacture of aluminum, sodium, magnesium, and calcium.

Water, in a high state of purity, possesses very little conductive power; in fact it is practically an insulating material. Kohlrausch gives a specific resistance of 25,000,000 ohms per $\overline{\text{cm}}^3$ for freshly distilled water. On accumulating impurities by exposure to the air for some time, the resistance may drop to one-twentieth of this amount.

Similarly, sulphuric acid, in a condition of absolute purity, has an exceedingly high specific resistance, tending to place it among the insulators. If, however, a certain amount of these two non-conductive substances be mixed together, the result is a material which has a power of conducting to a high degree. The question has naturally arisen as to whether it is the acid under the influence of the water or the water as influenced by the acid, or a combination of both, which produces the conductive power. In settling this point, we would be led into the realm of speculation and, for practical purposes in working with aqueous electrolytes, the common assumption may be followed that it is the substance which is dissolved in the water which possesses the conductive property.

Conductivity. One important characteristic of electrolytic conductors is that the order of conductivity is far lower than that of metallic conductors. The best conducting electrolytes, for example, have a specific resistance at least one million times as great as that of the average metallic conductor.

Another striking characteristic is the negative temperature coefficient which causes the resistance to decrease with increasing temperature.

It should be borne in mind that by no means all of the materials which dissolve in water produce electrolytes. Those chemical substances which on dissolving in water become conductive have been determined by trial and by measurements. Sugar and common salt are both soluble in water. The former, however, produces no electrolytic conductivity, while the latter does.

It has been found by trial that, in general, solutions of inorganic acids, salts, and bases conduct electrolytically, while the neutral organic compounds in solution do not conduct.

The degree of conductivity of an electrolyte depends upon a number of factors, including the chemical composition of the dissolved substance, the amount of such substance in solution, and the temperature.

A quantitative study of the relationship between the conductivity of a solution of a given substance and the amount of substance dissolved, reveals interesting and important features and furnishes the basis upon which modern theoretical views of electrolytic dissociation and conduction are based. However, for practical purposes of an elementary text, it may not be necessary to follow this line of study here.

THE ELECTROCHEMICAL CELL

Definitions. An *electrochemical cell* is a form of apparatus in which all industrial electrolytic processes are carried out. It may be defined as a combination of two metallic conductors, constituting the *electrodes,* and an electrolytic conductor, constituting an *electrolyte* which joins the electrodes. A suitable containing vessel is also an essential part.

The *anode* is the electrode at which the current enters the electrolyte, and the *cathode* is the electrode at which the current leaves the electrolyte.

The cell is *inactive* if no current flows, and it becomes *active* when the current passes, which in turn means that to be active it must be connected to an external source of electrical energy. This external energy may be obtained from any generator of direct current, such as a primary battery, a storage battery, or a dynamo.

Action Inside the Cell. *Diagram of Circuit.* A typical diagram of an active cell is shown in Fig. 1, where *d* is the dynamo, or other source of current; *r* is a rheostat for regulating the amount of current, or current density; *i* is an ammeter for measuring the current; and *v* is a voltmeter for measuring the voltage at the cell terminals; *s* is a switch for opening or closing the circuit. The arrows indicate the direction of the flow of current; *a* is the anode, and *c* the cathode.

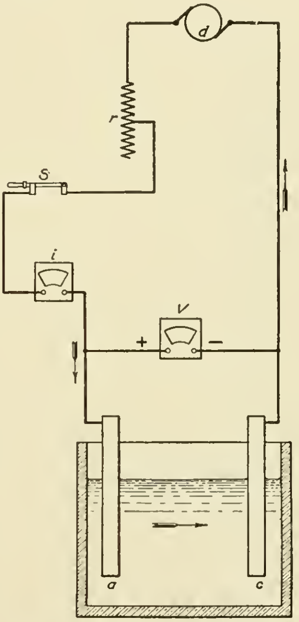


Fig. 1. Diagram of Electrolytic Cell

It will be noted that the positive (+) terminal of the voltmeter is connected to the anode, or positive pole, at which the current enters the cell, while the negative (−) terminal of the voltmeter is connected to the cathode, or negative pole. For this reason it is a common practice to use the terms "positive pole" and "negative pole" in place of the terms "anode" and "cathode", respectively. To avoid confusion, however, it is far better to employ the terms *anode* and *cathode* wherever possible and to learn to know instinctively that the anode designates the surface at which the current enters the electrolyte and that the cathode indicates the surface where the current leaves.

Method of Carrying Current. To determine in just what manner the electrolyte carries the current is the purpose of various theories which are not as yet capable of positive proof. It is a common con-

TABLE I

Positive and Negative Radicals of the More Common Compounds

SUBSTANCE	FORMULA	NEGATIVE RADICAL OR ANION	POSITIVE RADICAL OR CATHION
Aluminum chloride	$AlCl_3$	3Cl	Al
Ammonium chloride	NH_4Cl	Cl	NH_4
Barium chloride	$BaCl_2$	2Cl	Ba
Calcium chloride	$CaCl_2$	2Cl	Ca
Potassium chloride	KCl	Cl	K
Cadmium chloride	$CdCl_2$	2Cl	Cd
Magnesium chloride	$MgCl_2$	2Cl	Mg
Manganese chloride	$MnCl_2$	2Cl	Mn
Sodium chloride	NaCl	Cl	Na
Hydrochloric acid	HCl	Cl	H
Zinc chloride	$ZnCl_2$	2Cl	Zn
Hydrobromic acid	HBr	Br	H
Potassium bromide	KBr	Br	K
Hydriodic acid	HI	I	H
Potassium iodide	KI	I	K
Barium nitrate	$Ba(NO_3)_2$	$2NO_3$	Ba
Calcium nitrate	$Ca(NO_3)_2$	$2NO_3$	Ca
Nitric acid	HNO_3	NO_3	H
Potassium nitrate	KNO_3	NO_3	K
Silver nitrate	$AgNO_3$	NO_3	Ag
Sulphuric acid	H_2SO_4	SO_4	2H
Copper sulphate	$CuSO_4$	SO_4	Cu
Magnesium sulphate	$MgSO_4$	SO_4	Mg
Sodium sulphate	Na_2SO_4	SO_4	2Na
Silver sulphate	Ag_2SO_4	SO_4	2Ag
Zinc sulphate	$ZnSO_4$	SO_4	Zn
Potassium carbonate	K_2CO_3	CO_3	2K
Sodium carbonate	Na_2CO_3	CO_3	2Na
Potassium chlorate	K_2ClO_3	ClO_3	2K
Potassium hydroxide	KOH	OH	K
Sodium hydroxide	NaOH	OH	Na
Potassium chromate	K_2CrO_4	CrO_4	2K
Potassium bichromate	$K_2Cr_2O_7$	Cr_2O_7	2K
Potassium cyanide	KCN	CN	K
Potassium ferrocyanide	$K_4Fe(CN)_6$	$Fe(CN)_6$	4K
Potassium silver cyanide	$KAg(CN)_2$	$Ag(CN)_2$	K
Potassium oxalate	$K_2C_2O_4$	C_2O_4	2K
Sodium acetate	$NaC_2H_3O_2$	$C_2H_3O_2$	Na

ception that the current in passing through the electrolyte causes a bodily movement of some of the material in the electrolyte in the direction of the current and of a corresponding amount of other material in the reverse direction. Or, in other words, the materials held in solution dissociate into ions. Those *ions* which travel with the current and are deposited on the cathode are called *cathions* and those which go against the current and are liberated at the anode are *anions*.

Anions and Cathions. In order to determine what action will take place in a cell, it is important to know what materials constitute the anions and cathions.

From a study of chemistry, it is noted that the inorganic compounds such as are taken into solution in water, are composed of what are known as the *metal,* or *positive, radical* and an equivalent *acid,* or *negative, radical.* Table I gives a list of the more common materials with their respective anions and cathions.

From this table it is to be noted that the cathions consist almost entirely of metals, with the addition of the element hydrogen and of the compound NH_4; also that the anions consist of the electronegative elements, such as chlorine, bromine, iodine, and fluorine, and of various compound radicals, such as SO_4, NO_3, CO_3, OH, CrO_4, etc.

Faraday's Laws. The most important laws pertaining to electrolysis are what are known as Faraday's laws. They constitute the basis of all electrochemical calculations, determining just how much chemical action is produced by a given flow of current for a given time. These laws are as follows:

> (1) The amount of chemical effect produced during electrolysis is directly proportional to the product of the current and the time; that is, to the quantity of electricity which flows through the electrolyte.
>
> (2) When a current passes through an electrolyte, bringing about chemical changes at the electrodes, the quantity of each substance formed is directly proportional to the equivalent weight of the substance and to the quantity of electricity which has flowed through the electrolyte.

It is obvious that if one ampere flowing for one minute will deposit a certain amount of copper, two amperes flowing for one minute will deposit twice that amount. Also that the amount which a given current will deposit in ten minutes is ten times as great as will be deposited by the same current in one minute.

Electrochemical Equivalent. By knowing the *equivalent weight,* or, as it is more commonly termed, the chemical equivalent, of the material, the quantity of that material which will be liberated by a known amount of electric current can be readily calculated. Every substance, whether it be a chemical element or a chemical compound, has its *electrochemical equivalent,* just as it has a certain atomic

TABLE II

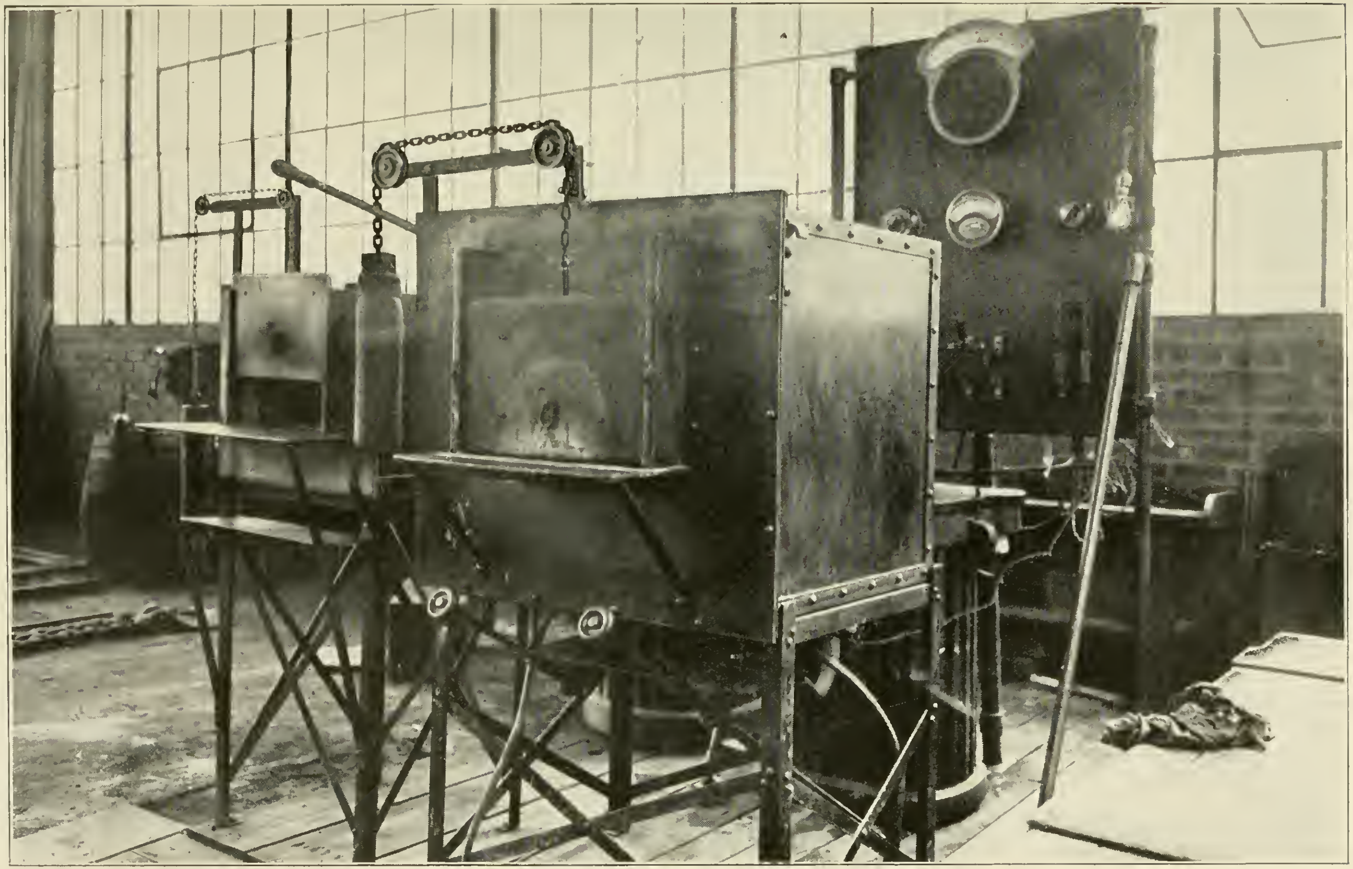
Constants of the Elements*

Name of Elements	Symbol	Valency	Chemical Constants		Electrochemical Constants			Commercial Constants "Result"	
			Atomic Weights	Chemical Equivalents	Per Coulomb (i. e. per amp. sec.) in mg. per sec.	Per Ampere Hour (i.e. 3600 Coulombs) in grams	Per Faraday (i.e. 96,540 Coulombs), grams	Per 1000 Ampere Years (i.e. 8760 hrs.) in metric tons	Per H. P. Year for one volt in metric tons
Aluminum. . . .	Al	III	27.10	9.03	.09354	.33674	9.033	2.950	2.201
Antimony.	Sb	III	120.20	40.07	.41509	1.4943	40.067	13.090	9.765
Arsenic.	As	III	75.00	25.00	.25898	.93233	25.000	8.167	6.093
Barium.	Ba	II	137.40	68.70	.71166	2.5620	68.700	22.443	16.742
Bromine.	Br	I	79.96	79.96	.82831	2.9819	79.960	26.221	19.561
Cadmium.	Cd	II	112.40	56.20	.59229	2.1322	56.200	18.678	13.934
Calcium.	Ca	II	40.10	20.05	.20770	.74772	20.050	6.550	4.886
Carbon.	C	IV	12.00	3.00	.031077	.11188	3.000	.9801	.7311
Chlorine.	Cl	I	35.45	35.45	.36723	1.3220	35.450	11.581	8.639
Cobalt.	Co	II	59.00	29.50	.30559	1.1001	29.500	9.637	7.189
Copper.	Cu	II	63.60	31.80	.32942	1.1859	31.800	10.388	7.749
Fluorine.	F	I	19.00	19.00	.19682	.70855	19.000	6.207	4.630
Gold.	Au	III	197.20	65.73	.68090	2.4512	65.733	21.473	16.019
Hydrogen.	H	I	1.008	1.008	.010442	1.03759	1.008	.329	3.2456
Iodine.	I	I	126.97	126.97	1.3153	4.7351	126.970	41.479	30.943
Iron.	Fe	II	55.90	27.95	.28953	1.0423	27.950	9.131	6.812
	Fe	III	55.90	18.63	.19279	.69404	18.633	6.090	4.543
Lead.	Pb	II	206.9	103.45	1.07164	3.8579	103.450	33.795	25.211
Magnesium. . .	Mg	II	24.36	12.18	.12617	.45422	12.180	3.979	2.968
Manganese. . . .	Mn	II	55.00	27.50	.28587	1.0291	27.500	9.015	6.725
	Mn	III	55.00	18.33	.18988	.68357	18.333	5.988	4.467
Mercury.	Hg	I	200.00	200.00	2.0718	7.4585	200.000	65.333	48.738
	Hg	II	200.00	100.00	1.0359	3.7292	100.000	32.667	24.370
Nickel.	Ni	II	58.70	29.35	.30404	1.0945	29.350	9.588	7.153
	Ni	III	58.70	19.57	.20273	.72983	19.567	6.393	4.769
Nitrogen.	N	III	14.04	4.680	.048480	.17453	4.680	1.529	1.141
Oxygen.	O	II	16.000	8.000	.082872	.29834	8.000	2.613	1.949
Platinum.	Pt	IV	194.80	48.70	.50448	1.8161	48.700	15.909	11.868
Potassium.	K	I	39.15	39.15	.40555	1 4600	39.150	12.790	9.541
Silicon.	Si	IV	28.40	7.10	.073549	.26478	7.100	2.319	1.730
Silver.	Ag	I	107.93	107.93	1.11805	4.02498	107.930	35.267	26.309
Sodium.	Na	I	23.05	23.05	.238775	.859590	23.050	7.530	5.617
Sulphur.	S	II	32.06	16.03	.16605	59778	16.030	5.237	3.907
Tin.	Tn	II	119.00	59.5	.61636	2.2189	59.500	19.438	14.501
	Tn	IV	119.00	29.75	.30818	1.1094	29.750	9.718	7.250
Zinc.	Zn	II	65.40	32.70	.33874	1.2195	32.700	10.683	7.970

*From "Electrothermal and Electrolytic Industries", Ashcroft.

weight; and in fact the electrochemical equivalent is closely associated with the atomic weight.

The *electrochemical equivalent* of a substance is the atomic weight divided by the valence and multiplied by a constant. This constant is a weight of hydrogen which will be liberated by a unit quantity of electric current. This constant is .00001036 grams, being the



HOSKINS ELECTRIC FURNACES FOR HEAT-TREATING TOOLS

The furnace at the left is for hardening carbon steel tools and for preheating high-speed steel tools. The furnace at the right is for hardening high-speed steel tools. Note Hoskins pyrometer at top of switchboard.

Courtesy of Hoskins Manufacturing Company

amount of hydrogen which is liberated by one coulomb or one ampere flowing for one second.

For purposes of practical calculation it is common to express the electrochemical equivalent of a substance in terms of the amount of material which is deposited by one ampere flowing for one hour's time. Table II gives electrochemical equivalents of various common elements.

If, for example, it is desired to know how much copper will be deposited by ten amperes flowing for two hours, a simple calculation based upon the value of copper shown in Table II can be made. It is $10 \times 2 \times 1.1859$, or 23.71 grams. Likewise, the same amount of current will liberate $10 \times 2 \times 1.322$, or 26.44 grams of chlorine.

Cathode Reactions. In observing the changes which take place at the cathode during electrolysis, various phenomena may be noted. If a suitable solution containing copper or nickel is used, copper or nickel will be deposited at the cathode, coating it over and growing to such thickness as is determined by the amount and duration of the current. Likewise, various other metals, such as gold, silver, iron, zinc, cobalt, and cadmium, may be deposited. This furnishes the basis of the electroplating industry. Some of the metals, on the other hand, will not be deposited out in the metallic state; for example, no one has yet succeeded in depositing metallic aluminum, neither can sodium, or potassium, or calcium, or various other highly positive metals be deposited from aqueous solutions. The reason for this is that these electropositive metals, at the instant they are liberated by the current, react chemically with the water to form other compounds. When sodium is deposited, it reacts chemically with the water, in accordance with the following equation:

$$Na + H_2O = NaOH + H$$

Instead, therefore, of metallic sodium being liberated, hydrogen is evolved and caustic soda is formed in the electrolyte. The electrolytic production of caustic soda and of hydrogen is thereby made possible as a result of electrolytic action supplemented by chemical action.

It should be noted, therefore, that the *cathion* may be deposited directly on the cathode, or it may unite chemically with the electrolyte.

Anode Reactions. In a similar manner the *anions,* upon being liberated, may be deposited on the anode, or may escape as a gas, or may react chemically with the electrolyte, or may unite chemically with the electrode material. Which of these various processes takes place depends largely upon the peculiar characteristics of the material involved. It is important to note that the materials at the instant of liberation are in a particularly active chemical condition, or in the nascent state. Perhaps the most noticeable action at the anode is a tendency for the liberated materials to attack or corrode the anode. Thus, for example, when a sodium chloride solution is electrolyzed between two iron electrodes, the chlorine which is liberated at the anode will attack the iron to form soluble iron chloride; in other words, the iron will go into solution. If it is desired to decompose salt for the production of chlorine, an *insoluble* anode material must be selected. Graphite is particularly serviceable for this purpose and is extensively used for chlorine production.

Soluble and Insoluble Anodes. We have then what are known as *soluble* and *insoluble* anodes, depending upon whether they withstand the action of the electrolysis. As a general rule, the metals are corroded when used as anodes. It is for this reason that deterioration of water and gas pipes takes place in the city streets where leakage current from electric railways flows from the iron surfaces into the earth. Dependent upon the anode solubility, the amount of metal in an electroplating solution is maintained at a constant value, the metal going into solution from the anode at the same rate that it is deposited out at the cathode.

Of the various metals, platinum is the one most commonly used when an insoluble metal is required. Graphite is insoluble in chloride solutions, while it is slowly attacked in certain other solutions. Lead peroxide and the black magnetic oxide of iron, previously referred to as being compounds which conduct metallically, have their principal use in electrolytic work because of their electrochemical insolubility.

ELECTROLYTIC REFINING AND RECOVERY OF METALS

Refining Copper. An important use of the electrolytic cell is found in the refining of certain metals, the most important of which is copper. Copper of high purity is necessary as a conductive material for electric power generation and distribution, and in the early days of the electrical industry, the only source of a sufficiently pure metal was the native metallic copper found in the Lake Superior region and commonly known as "lake" copper. The rapidity of electrical development made this source of supply entirely inadequate and it became necessary to draw upon the enormous deposits of copper ore found in the Western States. By the ordinary metallurgical methods of smelting, however, only an impure grade of copper could be produced, the highest purity not being greatly in excess of 98 per cent. A very small amount of alloying impurity in copper has the effect of greatly reducing its electrical conductivity and, therefore, high purity is of supreme importance. The desire of utilizing these Western ores, therefore, directed attention to the electrolytic method of refining. In fact, practically the only known method of making impure copper available for the electrical industry is by the electrolytic refining methods which have been worked out during the last quarter of a century.

Action in Experimental Cell. A simple experimental cell for refining copper can be constructed easily by dissolving copper sulphate crystals in water, adding a small amount of sulphuric acid, and then passing current through this solution, using an impure copper anode and a copper sheet cathode upon which the pure metal is to be deposited. The amount of copper which is deposited upon the cathode depends mainly upon the amount of current and the time of flow. The SO_4 anion which is liberated at the anode attacks the anode copper, forming copper sulphate and thus replacing the copper which is thrown out at the cathode. The amount of copper which goes into solution should, according to Faraday's laws, be equal to that which is deposited out at the cathode. The resultant action is then simply a transference of the copper from the anode through the solution to the cathode. The refining takes place because certain of the impurities in the anode are insoluble, such for example as silver, gold, and lead. Certain other impurities go into solution in the electrolyte, but are prevented from being deposited at the cathode because copper separates far more easily than do the other elements.

By-Products. The result of this refining operation is that certain of the impurities either remain attached to the anode or settle to the bottom of the cell as what is known as anode slime. Other of the impurities, such as arsenic and iron, gradually accumulate in the electrolyte until such quantity is reached that it becomes necessary either to throw the electrolyte away or put it through a chemical refining operation.

The electrolytic cell for the refining of metals has been likened to a series of screens through which the desired metal is sifted, leaving the impurities behind.

While the principal object in the refining of copper was to get the pure metal, it was soon noted that some of the impurities which settled to the bottom of the tank were of value, these metals being principally gold and silver. The subsequent recovery of these materials from the anode slimes furnished a great source of profit, and, in fact, copper refining has become important not only for the manufacture of pure copper but for the recovery of precious metals as well.

Refining of Metals Other Than Copper. *Silver.* It must not be assumed that, because copper refining by electrolysis is eminently successful, the electrolytic method may be similarly applied to the other metals. In fact the ordinary metallurgical methods are usually superior as to cost and availability. Electrolytic silver refining is carried out to some extent by what is known as the *Moebius* process, in which the anodes or impure silver bars are suspended in a filter cloth sack in an electrolyte consisting of silver nitrate slightly acidified by nitric acid.

From this electrolyte the silver is deposited in a loose crystalline state which tends to grow in tree-like formations toward the anode. To prevent this, each cathode is provided with a wood scraper which periodically removes the crystalline deposit of pure silver. This settles to the bottom of the tank, where it is subsequently removed.

Gold. Gold refining is likewise carried out to a certain extent, the anodes usually containing about 94 per cent of gold, 5 per cent of silver, and one per cent of copper and various other metals. The electrolyte consists of a solution of gold chloride with a small amount of free hydrochloric acid and a trace of gelatin added to improve the physical quality of cathodic deposit.

Baser Metals. While many attempts have been made toward electrolytic refining of common metals, such as zinc, tin, nickel, and iron, the difficulties are usually so great, or the other metallurgical methods so satisfactory, as to make the financial reward insufficient to warrant commercial development. The electrolytic refining of iron seems to offer some possibilities of industrial success, due to a certain demand for a specially high-grade material. Most of the electrolytic iron thus far produced has been used only for experimental purposes and in researches concerning the nature of iron and iron alloys.

From the experiments of the earlier electrochemists with the deposition of lead, there was a general belief that lead could not be deposited electrolytically in anything but a loose and spongy form. As illustrating the value of a detailed study of electrolyte materials, reference may be made to the interesting and important discovery that a dense heavy deposit of lead may be obtained by the use of a solution of lead silico-fluoride, $PbSiF_6$, with the addition of a trace of gelatin. This discovery led to the development of what is known as the "Betts Process" for lead refining, which is in extensive commercial use.

Electrolytic Recovery of Metals. One of the alluring prospects which has been held out in connection with electrochemistry is its application to the recovery of metals from the ores. It has been thought by many inventors that the electrolytic methods might compete with the smelting and wet extraction methods constituting general metallurgical practice, but more especially have inventors been directing their attention to the recovery of values from refractory or non-workable ores discarded in current metallurgical practice.

Gold from Sea Water. It has been known for a long time that sea water contains gold in such quantity that a cubic mile of the sea water taken at almost any locality contains a great wealth of this precious metal. It is also known that gold can be deposited from an aqueous solution by the passage of an electric current, and this fact has led to many attempts at the electrolytic recovery of gold from sea water. These attempts have all been failures through neglect to recognize certain fundamental laws of electrolysis. The gold which is in solution is probably present as gold chloride, but in exceedingly dilute solution. If this electrolyte is placed in an electrolytic cell, the gold will migrate very slowly toward the cathode.

The sea water contains chlorides of sodium and magnesium as well as various other dissolved substances and these also act as an electrolytic conductor carrying the current. In passing current then through such a cell, most of the current is consumed in decomposing the more abundant materials to the exclusion of the gold. In figuring the cost of electrical energy, the corrosion of the anode material, and the interest and depreciation of the investment tied up in the cell construction, there is no possibility of a sufficient gold recovery to repay even an exceedingly small fraction of the necessary expense.

Other Metals. Various complex ores of zinc containing lead and silver and certain other elements have resisted treatment by metallurgical methods and have constituted an attractive material for electrochemical work. Many other examples may be named, but as yet no notable commercial success has been achieved in the electrolysis of aqueous solutions for the extraction of metals from their ores. As to the electrolysis of fused electrolytes, the conditions are different, as evidenced by the aluminum industry to be described later.

General Features of a Recovery Process. To treat an ore or a waste product containing a metal necessitates, first, getting it into an aqueous solution. This may be done by treatment with an acid and then dissolving out the soluble compound. The next step is to treat these compounds in an electrolytic cell, depositing the metal upon the cathode from which it can be recovered. While the cost of leaching and extraction usually makes the process prohibitive, there are serious electrochemical difficulties, the chief of which is the difficulty of getting an insoluble and sufficiently cheap anode material. If a soluble anode material be employed, the expense caused by its corrosion may likewise become prohibitive.

The cost of electric energy involved is another important item. If, for example, in the deposition of zinc an insoluble anode be employed, the electromotive force at the cell terminals would be at least 3 volts. One pound of zinc, for example, weighing 456 grams would require 456 divided by 1.219, or about 374 ampere hours. At a pressure of 3 volts this makes a consumption of 3×374, or 1122 watt hours per pound of zinc. The cost of this energy would thus constitute a serious item of expense.

ELECTROPLATING

The most widely extended use of the electrolytic cell is in the art of electroplating. This is the art of coating a surface with a thin layer of dense adherent metal. Gold and silver are used mainly on account of the ornamental properties of these metals, while zinc is employed mainly on account of its protective action. Nickel has both ornamental and protective properties, and in fact each one of the metals capable of deposition has certain properties which give it some value in the electroplating art.

By Simple Immersion. As differing from the art of electrodeposition, we have what is known as the coating by simple immersion, whereby one metal may receive a deposit of another metal by simply dipping it into a solution containing some of the latter metal. For example, in dipping a piece of clean iron into a copper sulphate solution, a coating of copper is quickly produced. Copper when dipped into certain silver solutions, likewise attains a silver coating; and coatings of gold are applied to brass by this same method in the manufacture of cheap jewelry.

Coatings obtained by simple immersion are of little practical importance, however, due to the fact that the coatings at best are either exceedingly thin or are laid down in a porous and non-adherent condition. It is practically impossible to secure an adherent durable coating of copper on iron by this method. In fact, it is a general purpose of the electroplater to avoid solutions which will produce deposits by simple immersion without the aid of the electric current.

PRINCIPLES OF ELECTROPLATING PROCESS

Electroplating Cell. The electroplating cell consists usually of a tank or containing vessel for holding a suitable solution of the metal to be deposited. Metal bars from which the anodes are suspended are placed above the tank. These are connected to the positive lead of the dynamo or other source of current, while the bars from which the cathodes are suspended are connected to the negative lead from the dynamo.

It is customary to place an adjustable resistance or rheostat in series with each tank, so that the amount of current flowing through the tank can be adjusted in accordance with the amount of cathode surface. It is highly desirable, though by no means common practice, also to include an ammeter in series with each tank for measuring the current flow.

Current Supply. The current supply for plating may be derived from primary batteries, from storage batteries, or from a low voltage dynamo. The earlier art of electroplating was dependent almost entirely upon primary batteries, but the greatest advance in the art came with the introduction of the electric dynamo, whereby the cost of electrical energy was enormously reduced. For small scale and experimental work, a battery source may be most convenient; but for technical work, one of the highly efficient types of plating dynamos must be employed.

The voltage at which the dynamo must run is from three volts to six volts and sometimes even higher, dependent upon the general nature of the work to be done.

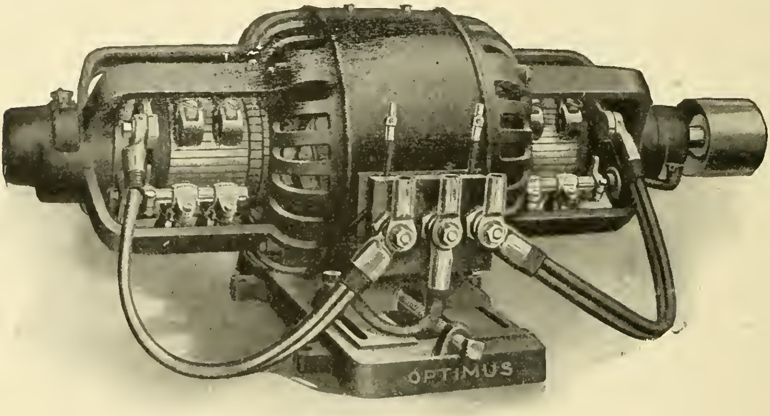


Fig. 2. Plating Dynamo with Double Commutator
Courtesy of Munning-Loeb Company

The low voltage plating dynamo is in general similar to the direct-current dynamo used for lighting and power purposes and differs in detail mainly in having a very large brush and commutator surface for carrying away, with as little heat as is possible, the large volume of current which is generated.

To give a large commutator and brush bearing surface, plating dynamos are frequently constructed with two commutators. Fig. 2 illustrates a modern type of plating dynamo. The leads running from the dynamo to the various tanks are usually of a very heavy copper wire or bar suitable for carrying a large volume of current without heating and to produce a minimum drop in voltage.

Fig. 3 shows the method of connecting a number of plating tanks fed from one dynamo.

Anodes. The anodes which are usually employed are of the soluble type and consist of the metal which it is desired to plate. In some rare cases an insoluble anode may be employed but this always involves a progressive change in the composition of the solution and interferes with simplicity of operation.

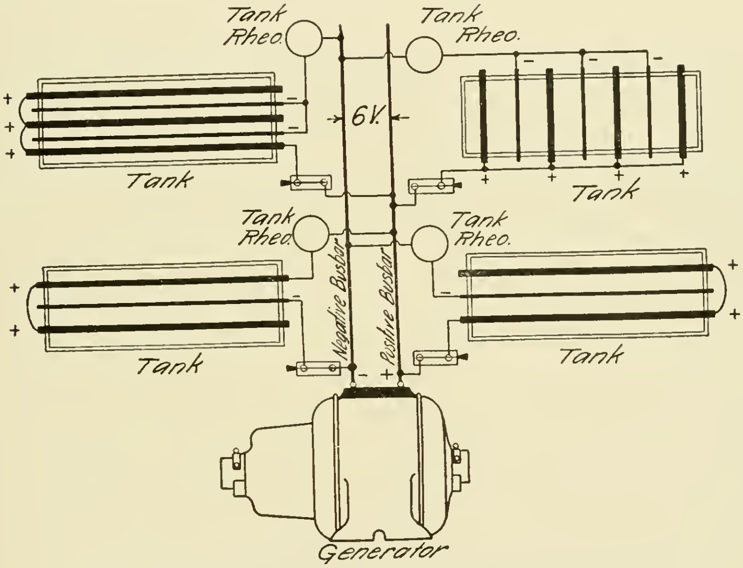


Fig. 3. Wiring Diagram for Tank Connections with Two-Wire Generator
Courtesy of Munning-Loeb Company

Factors in Successful Operation. *In General.* As to the general methods of operation, the electroplating process is simple, the metal being laid down by the action of the electric current, the thickness being dependent upon the amount of current and the length of time that the current flows. The process of electroplating is, however, beset with innumerable difficulties which the plater must know how to avoid. Much of the necessary information may be found in the various textbooks, but the successful practical plater is dependent largely upon the knowledge gained through extensive experience.

Quality of Deposit. The success of electroplating depends primarily upon the physical quality of the metal deposited. While in electrolytic refining coherence and density are not of greatest importance, density, coherence, and adherence are absolutely essential for protective and ornamental coatings. In general, there is a tendency for electrodeposits to become rough, especially after attaining some thickness. It is possible to secure metal deposits which are fern-like or tree-like or, in fact, imitative of almost all forms of vegetation, and to suppress these undesirable forms and to secure a dense smooth deposit constitutes much of the work of the electroplater. He finds he can regulate the quality of the deposit by various methods, such as the density of the solution, the composition of the solution, the current density, the temperature, the impurities, and various other factors.

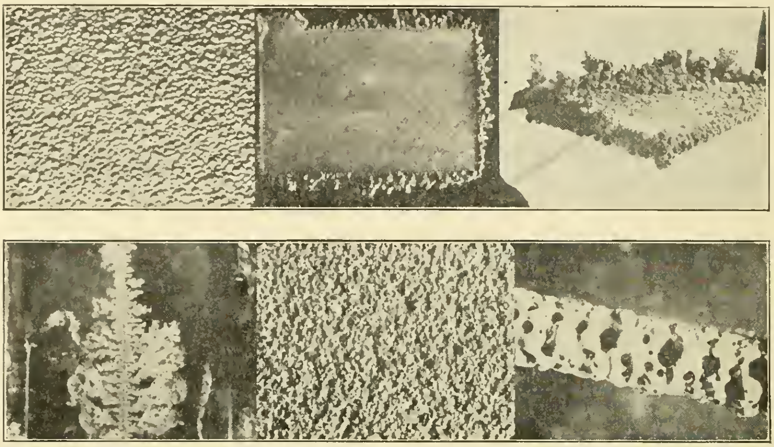


Fig. 4. Some Undesirable Forms of Electrolytic Deposits. Reading from Left to Right, Top: Nickel, Copper, and Iron. Bottom: Gas Bubbles in Heavy Nickel Deposit, Antimony, and Zinc
Courtesy of Metal Industry

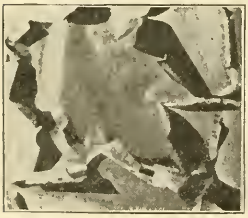


Fig. 5. Curling of Nickel Deposit
Courtesy of Metal Industry

Figs. 4 and 5 illustrate some of the forms which deposited metals may assume unless suitable precautions are observed.

Each metal has inherent qualities or tendencies as regards deposition. For example, nickel and iron tend to deposit in a finegrained dense state; copper is markedly crystalline; lead, tin, and silver tend to come down in a loose spongy or leaf-like formation; while platinum almost always deposits as an amorphous powder. It has taken about a century to develop the electroplating art to its present state in which practical working solutions are found for almost all of the metals. There is abundant opportunity, however, for further discovery of new electrolytes to overcome some of the present difficulties.

Addition Agents. A notable recent progressive step consists in the use of glucose or gelatin, or certain other inorganic materials, which, added to the ordinary plating solution, produce profound changes in the quality of the deposit.

Polishing. It is invariably desired that the resultant surface shall be smooth and polished. To secure the polish it is almost always necessary to subject the article to a buffing or burnishing operation. By the use of plating baskets and by the use of certain solutions, however, bright nickel and other deposits may now be secured.

The electroplater must know not only how to make up his original solutions from commercial materials, but even more important is his knowledge of how to maintain his solutions in constant working condition. If the anode metal does not go into solution in an amount exactly equal to that plated out at the cathode, the electrolyte will become depleted in metal and this must be supplied by dissolving up suitable materials. Careful attention is necessary to maintain a certain degree of acidity or alkalinity, as the case may be.

Influence of Current Density. The factor which the plater has chiefly under his control is the current density. It is usually desired that the metal shall be deposited as rapidly as possible, so that the output of a given tank shall be a maximum. There is a limit, however, beyond which the amount of current cannot be increased, and that is determined by the influence of the current density upon the quality of the deposit.

Each metal plating solution has a certain current density, usually expressed in number of amperes per square foot of cathode surface, beyond which the current cannot go. In nickel plating this is usually from five to ten amperes per square foot. In copper plating with a sulphate solution the current density may go far beyond this figure. In general, a current density under ten amperes per square foot is employed.

If the safe current density is exceeded, it produces a discolored deposit usually termed a *burned deposit,* this term being employed on account of the resemblance of the coating to an actual heating effect.

Adherence. The adherence of a metal deposit depends on characteristics of the metals involved as well as upon the care in doing the work. If a metal having a high coefficient of expansion is deposited upon one having a low coefficient, there will be a subsequent tendency for the coating to flake or peel off. This is a factor which is, of course, beyond the control of the plater; but a much more important factor which is entirely within his control is the method of preparing the surface which is to receive the plating. If this is properly done, the deposited metal may actually alloy with the metal to be coated; while if it is not properly done, the adherence will be less perfect.

The primary requisite for a metal to receive a deposit is cleanliness. Not only must the surface be freed from ordinary dirt, grease, rust, paint, or the like, but it must be chemically free from oxides or other tarnishing films, some of which are so thin as to be invisible. If a cleaned article is brought into contact with the hands, a contamination of the surface may be produced which will make a subsequent coating non-adherent. This illustrates the extreme care which must be employed. Oils and grease are removed by the use of a hot alkaline solution. Acid solutions and pickles are employed for the removal of oxides. Each metal has its own particular acid pickle which yields the characteristic and best results, but these details need not be considered here.

Principal Items of Expense. Grinding and polishing constitute the most costly part of the electroplating industry. It is a purely mechanical operation, by which abrasives or polishing materials are used either to remove adhering impurities from a surface or to give a surface the necessary smoothness. It is almost invariably true that during electroplating the surface becomes rougher instead of smoother and irregularities become accentuated rather than covered up. For this reason if a resultant smooth surface is desired, as smooth a surface as possible should be started with. Grinding and polishing before plating are, therefore, fully as important as the polishing and burnishing after plating.

The most important items of expense incident to electroplating are labor and materials. Labor is used mostly in the mechanical operations in preparing the surfaces or finishing the surfaces and in suspending the work in the tanks as well as in removing and rinsing. Where very small articles are to be handled, the labor and expense of stringing on wires would be prohibitive and for this reason there have been developed what are known as plating barrels or drums, by which a receptacle full of the small articles is rotated in a plating solution and the electrodeposit is formed while the articles are in a tumbling motion.

Fig. 6 illustrates a modern type of rotary plater in which nails or other small articles are plated without necessitating the stringing operation where each piece is handled separately.

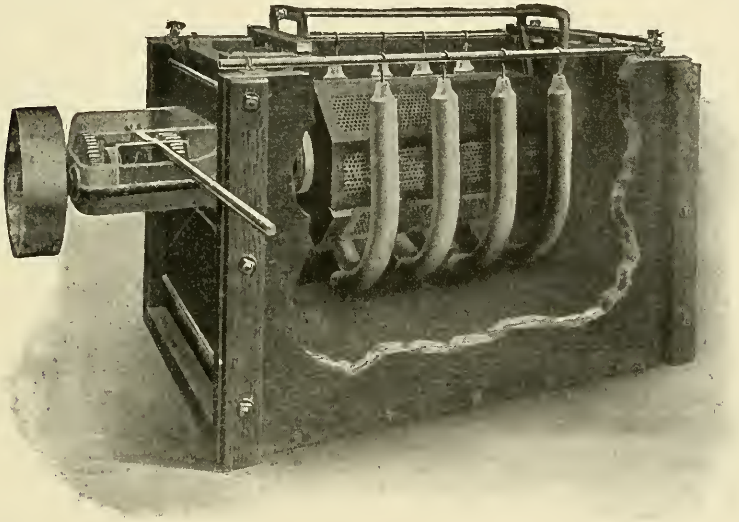


Fig. 6. Modern Rotary Plating Machine
Courtesy of Hanson and Van Winkle Company

WORKING SOLUTIONS FOR PRINCIPAL METALS

The following paragraphs give the essential details and satisfactory working solution for the deposition of each of the more important metals.

Copper. Copper is among the metals which are most easily deposited. A large number of different solutions are employed, but the action of the two typical ones will be described.

(1) *Acid Copper Solution.* The so-called acid copper bath may be made up according to the following formula:

Copper sulphate crystals (blue stone) ($CuSO_4+5H_2O$)	2 pounds
Sulphuric acid (H_2SO_4)	$\frac{1}{2}$ to 1 pound
Water	1 gallon

Copper anodes are used with this solution, and the electrolyte being highly conductive and the anode metal going into solution readily, a low voltage is required, usually somewhere between one and two volts. This depends upon the current density employed and upon whether the anodes and cathodes are far apart or close together.

The current density is usually from 10 to 20 amperes per square foot of cathode surface where the electrolyte is kept quiet. By rapidly circulating the electrolyte, however, much higher current densities may be employed while obtaining satisfactory deposits. With rapid circulation, current densities as high as 100 amperes and over may be employed.

This acid copper bath is used mainly for electrotyping and the deposition of copper in thick coatings. It cannot be employed satisfactorily for depositing directly on iron, because of the fact that iron throws the copper out by simple immersion and produces a loosely adhering deposit. When it is desired to copperplate on iron, the iron must be first given a preliminary coating from the so-called alkaline bath or the cyanide solution.

(2) *Alkaline Copper Solution.* Potassium cyanide is an exceedingly important chemical compound for electroplating use. It has the property of dissolving in water and then dissolving up various metal compounds, such as copper, gold, and silver, to produce excellent electrodeposits. The chief objection to its use is its deadly poisonous nature.

For preparing a cyanide copper bath, about $1\frac{1}{2}$ pounds of potassium cyanide is dissolved in a gallon of water. Three-fourths of this solution is warmed up and in it is dissolved copper carbonate to the saturation point. About 12 ounces of the carbonate will thus dissolve. After pouring off the clear liquor, the remaining one-fourth of the original cyanide solution is added and the electrolyte is ready for use.

Copper anodes are employed and an electromotive force of from 3 to 5 volts is necessary to get the results. A current density of from 20 to 30 amperes per square foot may be used, although in operating under these conditions the amount of copper deposited is much less than is indicated by Faraday's law.

Nickel. The nickel bath in most general use is a saturated solution of the so-called double nickel salts. This consists of nickel ammonium sulphate $[(NH_4)_2.SO_4NiSO_4+6H_2O]$, twelve ounces of which will dissolve in one gallon of water. Nickel anodes, usually in the form of an impure cast nickel, are employed.

Some recent changes including the use of chlorides have resulted in improvements, but the old standard solution is in almost universal use.

In starting a batch of work, it is customary to employ a voltage of from 2 to 6 volts for a few minutes and then reduce to 2 or 3 volts, or even less. A current density of less than 10 amperes is all that can be economically employed. Too high a current density results in a black or burned deposit of nickel.

The above are simply illustrations of electroplating baths and are typical of those used for the deposition of zinc, silver, gold, etc.

PLATING NON=CONDUCTING BODIES

An interesting branch of the electroplating art has developed recently and has attracted marked attention on account of the novelty and beauty of the work which is being done. Fig. 7 shows how silver has been deposited upon glass and illustrates one of the numerous applications of a metal coating to a non-conductive material. Lace and other fabrics are being metallized; small animals, insects, flowers, leaves, and the like, can be coated electrolytically and thus be perpetuated in form and given the beauty of color through the range of those colors that lie under the control of the electroplater.

Rendering Surface Conductive. An essential step in the deposition of metals on non-conductive materials is first to render the surface conductive. This can be done in numerous ways; the best known being that illustrated by the practice of the electrotyper who takes a wax impression or mold from a form of type or metal design to be duplicated. This wax form is carefully dusted and brushed with a layer of high-grade conductive graphite, which, when applied to the mold, makes it appear like stove polish. This is the conductive surface which must constitute the starting point for the shell of copper which is subsequently to be deposited. For fabrics, flowers, leaves, or the like, the graphite will not adhere until first a layer of shellac or other sticky material is applied.

To avoid the use of graphite and the troublesome methods of applying, various chemical processes have been devised. A preliminary metal coating is obtained by dipping the article into a solution of a metal which is easily reducible. The wet surface is then treated with a reducing agent to throw out the metal, after which the plating can proceed by the ordinary chemical process. A solution of silver or platinum is suitable; phosphorus, pyrogallic acid, and various other reducing agents may be employed.

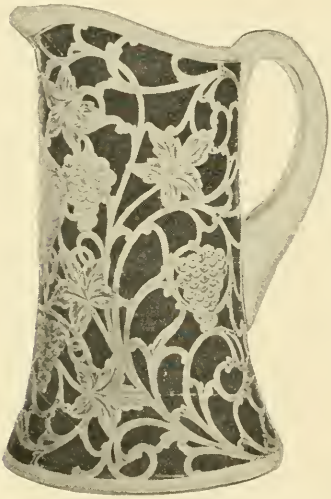


Fig. 7. Silver Deposit on Glass
Courtesy of Metal Industry

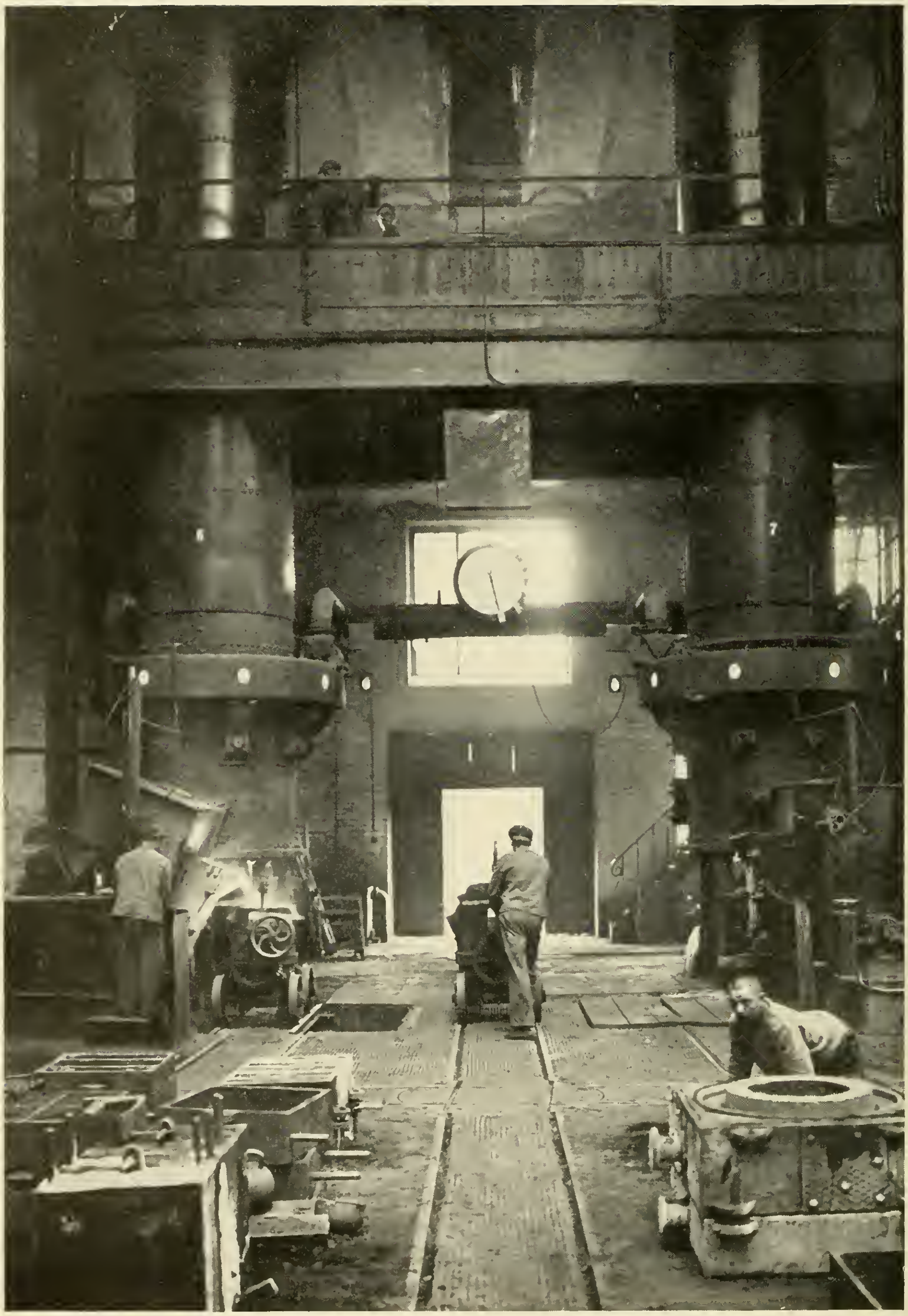
Plating on Glass. For plating on glass where the demand is for ornamental effect as well as a strongly adherent deposit, the glass may be rendered conductive by applying a metal paint, such as finely ground silver in turpentine, and then heating in a reducing atmosphere, under which conditions the silver will actually fuse to the glass. After cooling down, the glassware is wired in the ordinary way and put into the plating tank where the metal is deposited to the desired thickness.

DECOMPOSITION OF SALT SOLUTIONS

SODIUM CHLORIDE

Salt, NaCl, is a low priced and abundant material, which upon electrolytic decomposition may produce a number of valuable products for which there is a ready market. The apparent profits have attracted numberless inventors and, out of a large number of cells and processes which have been patented, a few have attained notable industrial success.

Decomposition of Solution. As explained on pages 41 to 44, the simplest and most direct way of decomposing salt is by the



NEW CUPOLA FOR POURING MOLTEN METAL IN THE FACTORY OF GASMOTOREN-FABRIK DEUTZ, AT COLOGNE

Photograph by Underwood & Underwood, New York fusion process, electrolysis yielding sodium and chlorine. But the great difficulties have confined most of the electrolytic work to the decomposition of aqueous solutions of salt.

Illustrative Experiment. A simple experiment, easily performed, will illustrate one practical application of sodium chloride electrolysis. A solution of salt in water, about five to ten parts to one hundred of water, is placed in a glass or other non-conducting vessel, Fig. 8. Two graphite electrodes are inserted and a direct current is caused to flow for an hour, at a current density of from ten to twenty amperes per square foot of anode surface. After the solution has then been electrolyzed, it has remarkable disinfecting and bleaching properties. A piece of colored cloth may be whitened, and one quart of the solution may sterilize a hundred thousand quarts of contaminated drinking water. Offensive odors may be quickly destroyed by the remarkable oxidizing power of this liquid.

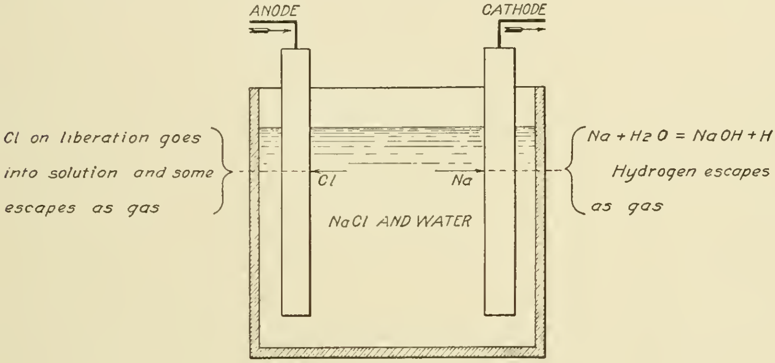


Fig. 8. Section of Electrolytic Cell Showing Decomposition of Sodium Chloride

As a result of these properties, this electrolytic cell has a field of usefulness in laundries; in textile mills; for purification of city water supplies; for disinfecting public swimming tanks; for treatment of sewage, for hospital use, and for many other purposes. A notable achievement has been the purification of an island in New York harbor which had been for years a dumping place for garbage, and which had become a public nuisance from the odors evolved. The purification was effected by electrolyzing sea water in wood tubs, using platinum anodes, and then pumping this solution on the land.

On account of the simplicity and effectiveness of the process, much attention has been drawn to it, and it naturally follows that extravagant and unwarranted claims have been made for it.

The oxidizing power of the electrolyzed salt solution is dependent upon the presence of sodium hypochlorite, $NaOCl$. This is similar in composition and chemical action to so-called chloride of lime or bleaching powder, which is calcium hypochlorite, $Ca(OCl)_2$.

Action in Cell. A study of the chemical changes which take place in this type of electrolytic cell, shows how sodium hypochlorite and various other substances may be produced.

$$Na+H_2O=NaOH+H \qquad (1)$$

$$2NaOH+2Cl=NaOCl+NaCl+H_2O \qquad (2)$$

or

$$6NaOH+6Cl=NaClO_3+5NaCl+3H_2O \qquad (3)$$

While there are numerous reactions which take place, the simplest and most important are those set forth in equations (1), (2), and (3).

The primary action of the electric current is to draw the chlorine ions toward the anode, and the sodium ions toward the cathode where they are liberated in an amount to agree with Faraday's law. The sodium cannot exist in the free state in contact with water, hence the reaction (1) takes place by which hydrogen is liberated as a gas, and a solution of sodium hydrate or caustic soda is formed. This is very soluble and diffuses throughout the electrolyte.

The chlorine which is liberated at the anode is soluble to some extent in the electrolyte, and it is only when liberated rapidly that some of it escapes as a gas into the atmosphere. There is, however, a strong affinity between chloride and sodium hydrate, and a chemical action shown by equation (2) takes place; that is, some sodium hypochlorite, $NaOCl$, is formed, together with an equivalent amount of salt and water.

If there is an excess of sodium hydrate, and the temperature is raised, the reaction becomes that shown in equation (3) where sodium chlorate, $NaClO_3$, is formed, together with salt and water.

The conditions can be regulated so as to favor either one of the reactions. That is, either hypochlorite or chlorate can be produced at the will of the operator, by variation of temperature, density of solution, and duration of electrolysis. Both of these materials have strong oxidizing power and both have important technical applications.

It is evident that the decomposition of potassium chloride, KCl, may be effected in the same manner as the sodium chloride, and by its decomposition practically all of the potassium chlorate of commerce is now produced. This is a material used extensively in the manufacture of matches, explosives, and for other purposes where a strong oxidizing agent is needed.

MANUFACTURE OF HYPOCHLORITES

Chemical Action. As indicated above, the production of sodium hypochlorite takes place in accordance with the equation

$$2NaOH+2Cl=NaOCl+NaCl+H_2O$$

As the process continues there is a steadily increasing amount of sodium hypochlorite in the solution and, like the salt, it may in turn be decomposed by the current. When this occurs oxygen is liberated at the anode. Therefore it is possible to attain only a certain strength of solution before the hypochlorite is decomposed as rapidly as formed, and for the sake of economy of energy the concentration of hypochlorite is not usually carried much beyond ten grams of active chlorine per liter of solution. In using this solution for bleaching and disinfecting purposes there is a considerable consumption of undecomposed salt which is necessarily lost, and which adds to the cost of the process unless a very cheap source of salt, such as sea water, is employed. The important items of cost in sodium hypochlorite production are the following: salt, which is decomposed together with that which accompanies the hypochlorite solution; electrical energy; and anode renewal. Since oxygen is liberated at the anode, and since carbon and graphite corrode under such conditions, the anode loss may be considerable. The cost of electrolytic hypochlorite is usually greater than that at which an equivalent amount of bleaching powder can be purchased. Nevertheless on account of convenience, cleanliness, and greater effectiveness of sodium hypochlorite over calcium hypochlorite, this type of cell has extensive use.

Commercial Electrolyzers. Among the types of commercial electrolyzers for hypochlorite is the one illustrated in Fig. 9. This shows a supply tank for dilute salt solution, feeding in a steady stream into the stoneware trough or electrolyzer. The overflow from this tank carries the hypochlorite solution into the larger rectangular storage tank below.

Since a pressure of about 5 volts is all that is needed between the anode and cathode, if current be taken from an ordinary lighting or power circuit, usually carrying a pressure of 110 volts, a rheostat to reduce the pressure at the cell terminals to 5 volts will be necessary. Since this is exceedingly wasteful of electric energy, it is avoided by placing a suitable number of cells in series so that little or no rheostat regulation is necessary. This is accomplished in the apparatus illustrated by placing a number of partitions of graphite plates spaced evenly along the trough and separated by insulating cleats. The end plates are connected to the high voltage source of current.

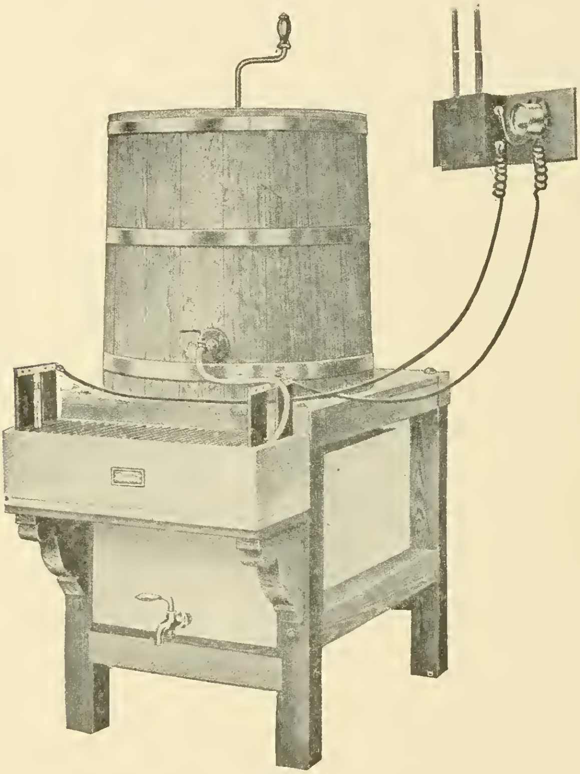


Fig. 9. Chlorinator, or Electrolyzer, for The Decomposition of Salt
Courtesy of the Valhalla Company

This construction is illustrated diagrammatically in Fig. 10. Fourteen compartments are shown, divided by graphite plates. Each compartment acts as an electrolytic cell, the electric current flowing in at the left end plate, and the left-hand side of the next plate acts as the corresponding cathode. The right-hand side of this same plate serves as the anode for the next compartment, and so on. This construction serves as a simple method of connecting cells in series without using a containing vessel for each pair of electrodes.

The salt solution flows downward between plates *1* and *2*, under plate *2* which is spaced a short distance from the bottom, upward between plates *2* and *3*, over plate *3* and then downward, and so on through the electrolyzer. The rate of flow of the solution is adjusted so that by the time it has passed through the last compartment it has been electrolyzed to the desired strength.

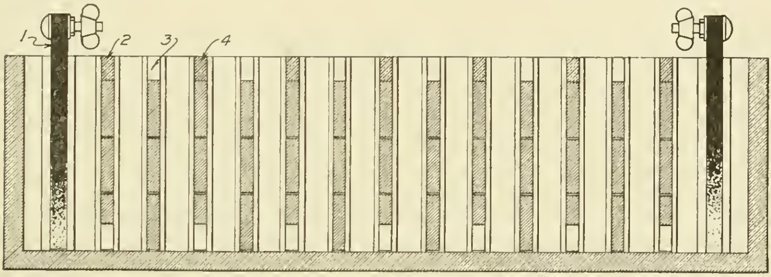


Fig. 10. Section of an Electrolyzer for Salt Solutions

MANUFACTURE OF CHLORINE AND CAUSTIC SODA

A process of far greater industrial importance than the production of sodium hypochlorite is the electrolytic decomposition of salt solutions for the manufacture of chlorine and caustic soda. The chlorine which is liberated is absorbed by lime in the manufacture of bleaching powder, or it may be taken up by lime solution to form a hypochlorite bleach liquor.

Practically all of the bleaching powder now on the market is an electrochemical product. Paper mills and other larger users of bleaching powder have installed, or are installing, electrochemical plants for this purpose. Caustic soda, which may be considered a by-product of this industry, is in great commercial demand and electrolytic caustic has largely replaced the products of the old methods.

Difficulties. In order that the electrolytic cell may deliver chlorine and caustic, it is evident that the construction and operation must be such as to prevent these materials coming together within the cell. Otherwise there would be formed sodium hypochlorite, which is decidedly detrimental; in fact the most effective test of the value of the electrolytic cell is the freedom from hypochlorite within the cell.

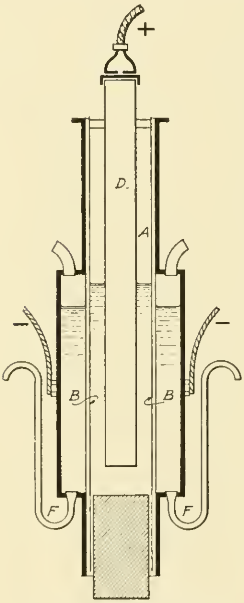


Fig. 11. Townsend Diaphragm Cell

Since the cathode product is extremely soluble in the electrolyte and the chlorine liberated at the anode also has considerable solubility, the problem of keeping these products separate is more difficult than is the separation of oxygen and hydrogen in the electrolytic decomposition of water. Several successful methods of effecting this have been devised, the principal ones being the use of some kind of a *diaphragm*, and the use of *mercury* as the cathode material.

Methods. *Diaphragm Cells.* As illustrating one of the several types of successful diaphragm cells, the Townsend cell may be referred to. This is employed in a large plant located at Niagara Falls.

The cell construction is shown diagrammatically in Fig. 11. The central compartment *A* contains the graphite anodes *D*. The anode channel is made up of a U-shaped framework of cement construction, the sides being closed by a sheet asbestos diaphragm *B* of special construction. On the outside of the diaphragm *B*, iron grids are placed and bolted tightly to the framework. On the outside of the cathode sheets are channels for the collection of the caustic soda. The particularly novel feature of this cell is that the two outer channels are filled with kerosene oil. The caustic soda solution which is formed at the cathode trickles through the diaphragm and sinks through this layer of oil and is drawn off through outlets *F*. This oil together with the diaphragm is intended to secure the complete removal of the caustic from the anode liquor. The brine solution to be decomposed is introduced into the anode chamber and the rate at which the solution flows through the oil is determined by the height of the liquid in this compartment with respect to the height of the oil column in the outer compartments.

The removal of the alkali is so effective that very high current densities can be used and still maintain high current efficiency. These cells can be constructed to use 2500 amperes each. The operation of the cell shows a current efficiency of from 90 to 95 per cent, operating at a pressure of from $4\frac{1}{2}$ to 5 volts per cell. The caustic which is drawn off from the cathode channels is a 15 per cent solution with an equal amount of undecomposed salt. The distinguishing feature and greatest limitation of all types of diaphragm cells are that the cathode solution which is drawn off consists of a mixture of both salt and caustic. A separation of these materials is necessary to put the caustic into a marketable condition and to prevent unnecessary waste of salt. This is accomplished by evaporation, the salt crystallizing out as the solution is concentrated.

Mercury Cells. Mercury has a remarkable property when used as the cathode in a salt solution, which is of great interest from a scientific standpoint and of great value from an industrial standpoint. When sodium is liberated on most cathode surfaces, it immediately unites with the water of an electrolyte to form caustic soda and liberate hydrogen. If, however, the cathode is mercury, the mercury absorbs the sodium before it has time to react with the electrolyte. It takes it in the form of an alloy or amalgam up to several per cent of its own weight. The completeness with which the sodium is taken up by the mercury depends somewhat upon the temperature, but more especially upon the purity of the mercury.

If this lead mercury amalgam be removed from the cell and placed in another compartment, it may be made to give up its sodium by using the amalgam as the anode. The sodium then goes into solution and forms sodium hydrate and liberates hydrogen upon the cathode. A simple method for making the amalgam act as an anode is to bring in metallic contact with it an electronegative material such as carbon or graphite.

The Castner cell is one of the oldest and most successful of the mercury type. Its construction is shown diagrammatically in Fig. 12, where it is indicated that the cell is divided into three compartments by two vertical partitions extending almost to the bottom of the cell, but not making a tight joint therewith. *A* and *C* constitute the anode compartments in which graphite anodes are employed. A layer of mercury rests on the bottom of the cell, making a seal beneath the two vertical partitions. The current is conducted away from the cell through the iron cathode in channel *B*. The current to flow through the cell must pass from the anode through the brine solution, thence to the mercury, and from the mercury through the caustic solution in compartment *B*, then to the iron cathode, and thence from the cell. The sodium mercury amalgam is formed in the anode compartments and this amalgam is transferred to the central compartment by a slow rocking motion which is given to the cell. The amalgam, therefore, surges back and forth, and while passing through the central compartment acts as anodic surface.

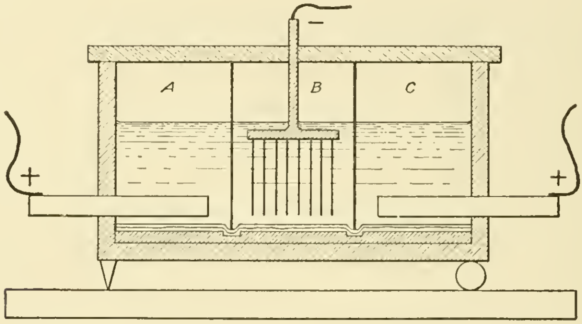


Fig. 12. Castner Mercury Cell

The actual operation of this cell introduces various complications which need not be described here, but the cell has been very successful from a commercial standpoint in producing chlorine and caustic soda of high purity. An obvious limitation on the construction is the necessity of rocking the entire cell and this feature has been avoided in the construction of another successful type of mercury cell known as the Whiting cell.

The cell body is a stationary, massive construction of concrete in which the mercury rests in thin layers in the anode compartments.

There are a number of divisions to the anode compartments and the mercury from each of these devices is discharged intermittently and in rotation into the oxidizing chamber where it comes in contact with graphite plates against which it gives up its sodium to the caustic soda solution. After the sodium has been extracted, the purified mercury is elevated by a stoneware wheel so that it flows back again into the anode compartments. The construction of this cell is illustrated in Fig. 13, and Fig. 14 shows a large sized working plant of this construction. A cell 6 feet square takes 1400 amperes at a voltage of about 4 volts. A pure caustic is produced and, on account of the high current efficiency, there is little hypochlorite production and, therefore, small anode loss.

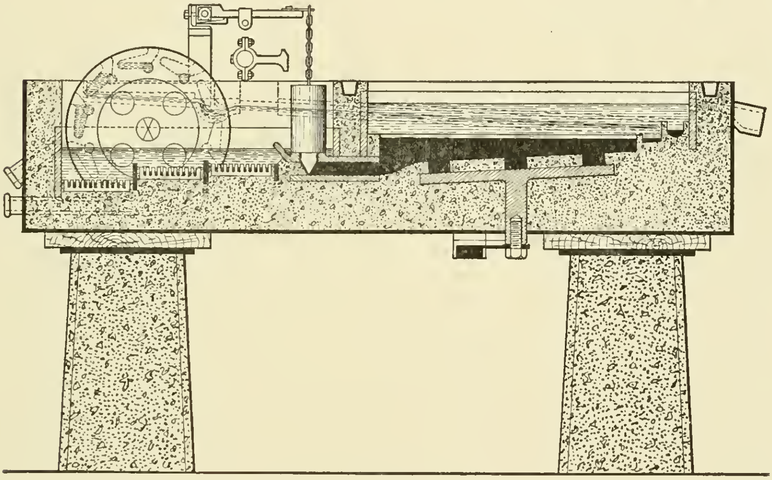


Fig. 13. Cross Section of Whiting's Electrolytic Cell

Relative Advantage of Mercury and Diaphragm Types. In view of the rapidly extending use of cells for decomposing salt, there is much discussion as to the relative merits of the mercury and diaphragm types of cells. The most important advantage of the former is its ability to produce a pure caustic soda solution, thus avoiding the expensive plant and costly operation of removing the salt from the caustic. On the other hand, the diaphragm process has the apparent advantage of cheaper cell construction, since the use of the costly mercury is avoided. Many other factors of lesser

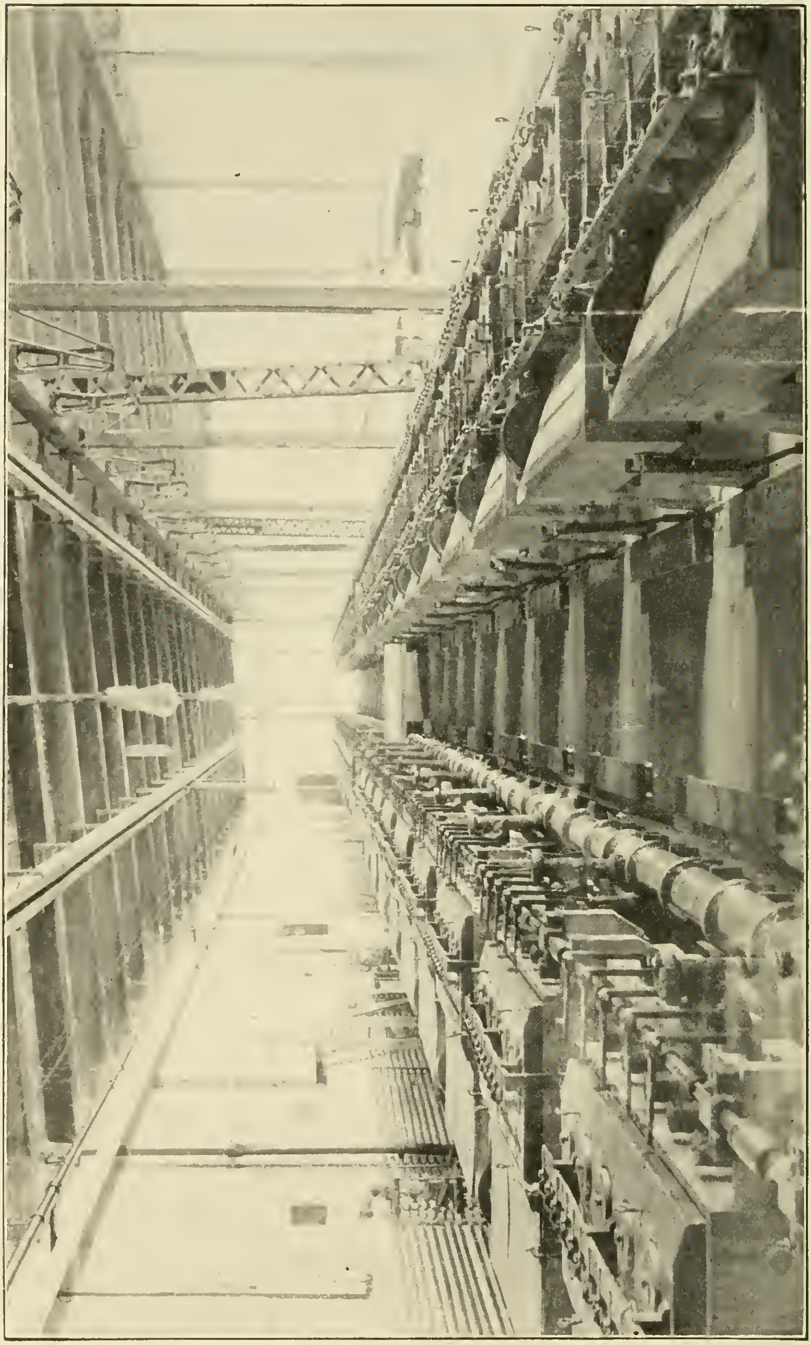


Fig. 14. An Installation of Whiting Cells in Operation

importance must be taken into account in considering the relative merits of the two types of cells, including the depreciation, anode renewal, cost of salt, cost of power, labor, etc. Whether or not one cell has the advantage of the other depends to some extent upon local conditions.

ELECTROLYTIC HYDROGEN AND OXYGEN

Uses of Hydrogen and Oxygen. Hydrogen and oxygen have extensive industrial applications. In addition to their many uses in chemical manufacture, these two gases are coming into extensive employment for oxy-hydrogen welding, and for other metallurgical operations. Oxygen is also used for similar purposes in connection with acetylene, and other hydrocarbon gases. Hydrogen is an excellent chemical reducing agent, and one of its large applications is for aeronautic use.

Hydrogen is given off at the cathode as a by-product in the decomposition of salt solutions and in various other electrolytic processes, and is usually regarded as a waste product. Oxygen is of greater value. It is produced to some extent by the liquefaction of air and its subsequent distillation. In this case it is mixed with a small amount of nitrogen but enough to prevent its most efficient use in attaining high temperatures in combustion operations. The pure gas can be made most economically by the electrolytic method, and the simultaneous production of both oxygen and hydrogen constitutes a profitable electrolytic industry.

Cells for Decomposing Water. Electrolytic cells of various types have been developed. They all employ either a sulphuric acid, or a sodium or potassium hydrate solution as electrolyte. Where the acid solution is used, lead is the material used in the cell construction; while with the alkaline electrolyte, iron is employed. This choice of materials is made because of the insolubility of lead and of iron in the respective solutions. It is obvious that insoluble anodes must be employed to allow the escape of oxygen.

Separation of Gases. An important point to be attained in water decomposition is that the anode and cathode products be kept as completely separated as possible. The bubbles of hydrogen coming off the cathode surface must not mingle with the oxygen bubbles from the neighboring anode surface. Otherwise impurity of products results and, what is of greater importance, a liability of explosion is produced. Numerous fatalities have resulted through inadequate precaution in this respect.

The electrodes must be placed as near together as practicable to reduce the resistance and the power consumption to an economical figure.

A 20 to 30 per cent sulphuric acid solution has a better conductivity than a 10 to 25 per cent alkali solution. On the other hand, it takes a somewhat higher electromotive force to liberate oxygen and hydrogen from the former solution, so that electrolyzers using the caustic soda or caustic potash have a slightly lower energy consumption than have those using the acid. The current efficiency approaches close to 100 per cent; that is, the oxygen and hydrogen are liberated in almost exact accord with Faraday's laws. This is essential to produce gases of the highest purity—about 99 per cent pure. Since the acid or alkaline is added to the electrolyte to give the conductivity to it and water alone is decomposed, it is necessary to add distilled water from time to time to replace that electrolyzed.

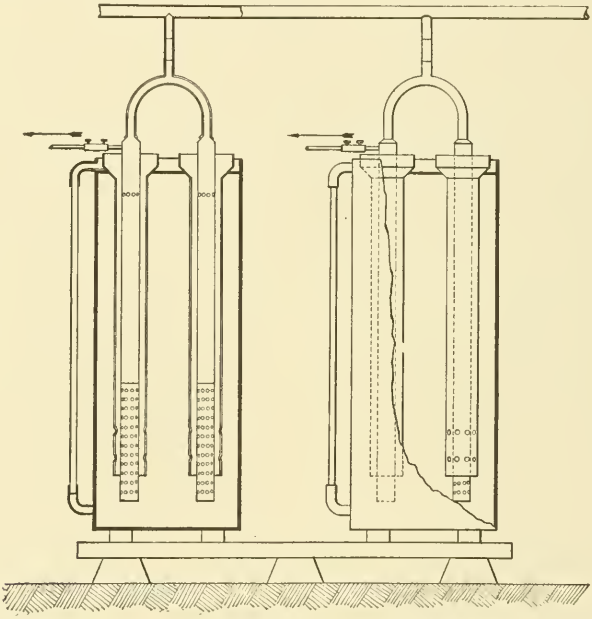


Fig. 15. Sections of Schoop Electrolyzer

Types of Cells. Among the various types of electrolyzers employed are the following:

Schoop. The Schoop system uses sulphuric acid and cylindrical lead-lined vats containing a number of vertical electrodes. These are in the form of long tubes filled with fine lead wire to increase the active electrode surface, each electrode being surrounded by a cylindrical tube of non-conductive material open below and perforated toward the bottom to allow the flow of current. The gas generated inside of this tube passes upward, where it is collected. This apparatus is illustrated in Fig. 15.

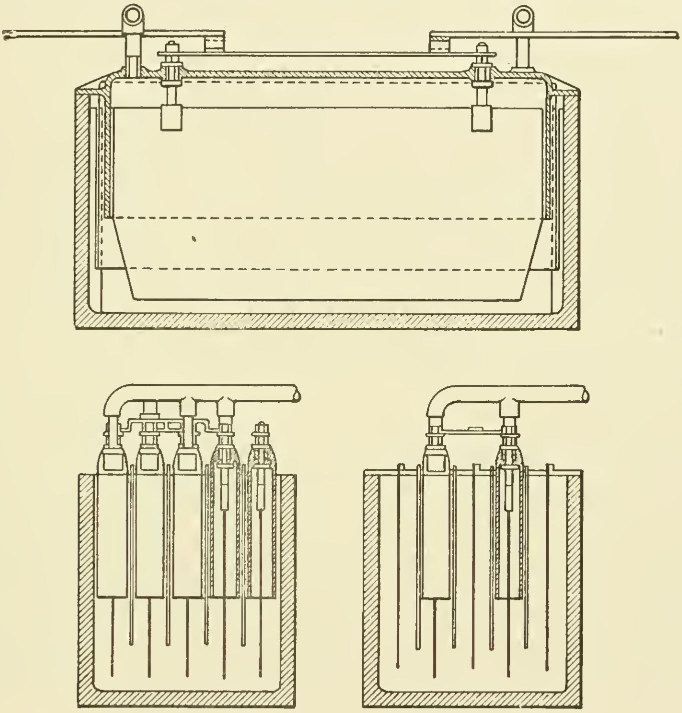


Fig. 16. Sections of Schuckert Electrolyzer

Schmidt. The Schmidt electrolyzer uses an alkaline electrolyte and the construction resembles a filter press. The electrodes are iron plates corrugated and are separated by diaphragms of asbestos with rubber packing around the edges. The purpose of this diaphragm is to keep separate the anode and cathode gases.

Schuckert. Another illustration of the alkaline type of cell is known as the Schuckert. In this an iron trough is divided into a number of compartments by vertical partitions of an insulating material extending from the top three-quarters of the way down the cell. These compartments contain alternately iron anodes and cathodes. Iron hoods suspended between the partitions carry off the gases. The construction of this cell is shown in Fig. 16.

A full sized plant equipped with International Oxygen Company cells is shown in operation in Fig. 17. For these cells a pressure of from 2½ to 3 volts and a current of 600 amperes is required.

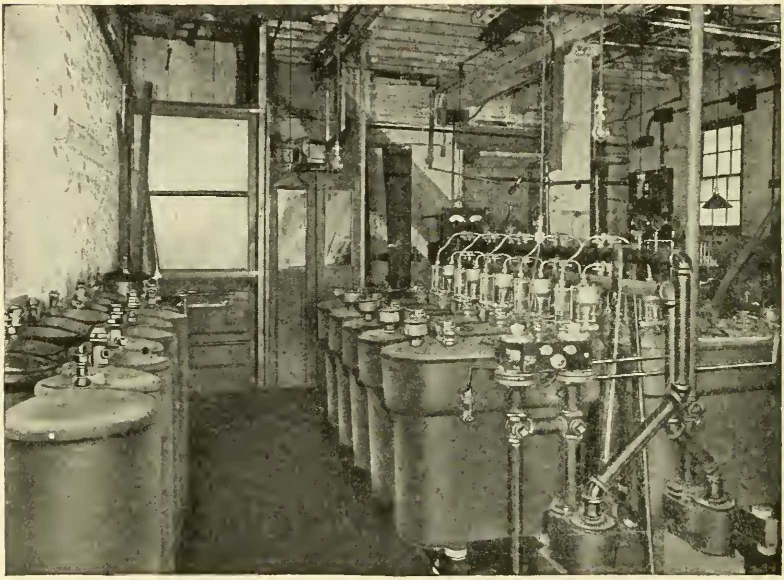


Fig. 17. Installation of an Oxygen-Hydrogen Plant
Courtesy of International Oxygen Company

Plant Equipment. An essential part of any electrolytic plant is a high pressure pump which is used to compress the gases into tanks for storage, although when the gases are to be used where manufactured, large tanks such as are used in gas works may be sufficient. Precautions against explosions must be carefully observed. In operating the compressor oil is not permissible for cylinder lubrication on account of the possibility of the oil getting into the oxygen and forming an explosive mixture. Glycerine is commonly employed for this purpose. Among other safeguards is the use of either an iron tube kept at a red heat or a tube filled with platinum sponge, or similar contact material. The gases from the electrolytic tanks will pass through such tubes, and whatever hydrogen there may be in the oxygen, or whatever oxygen there may be in the hydrogen, is consumed in producing water, and the purification is thus effected.

The gases when used for blow-torch purposes are passed through water-cooled funnels to prevent any possibility of the flame traveling backward into the tanks.

In view of the improvements being made and the high economy of the process, the electrolytic generation of oxygen and hydrogen promises to become an industry of great importance.

FUSED ELECTROLYTES

The majority of chemical compounds which are solid at ordinary temperatures become conductive when heated up to and beyond the melting points. The nature of this conductivity is usually electrolytic; that is, the molten materials are electrolytes which are capable of undergoing decomposition during the passage of a direct current. The conductivity of these materials is usually of about the same order as that of aqueous solutions.

The fact that we have molten electrolytes is of considerable technical importance, for upon it is based the recovery of various metals which would decompose water and, therefore, be unrecoverable by use of an aqueous solution. The aluminum industry is based upon the decomposition of a fused aluminum compound. The production of calcium, of sodium, and of magnesium is likewise dependent upon the decomposition of fused compounds of these respective metals.

MANUFACTURE OF SODIUM PRODUCTS

Fused Salt. The chemistry of the decomposition of melted salt is much simpler than is the chemistry of decomposition of aqueous solutions of salt. The electrolyte consists of only two elements: sodium and chlorine. Salt can be melted at a temperature of about 900° C. (a bright red heat). When placed in a suitable container and with an anode of carbon and graphite and a cathode of iron or other suitable metal, the sodium is liberated at the cathode and the chlorine at the anode. These two elements being liberated have nothing with which to react, as in the case of aqueous solutions, and they will thus be recovered in the free state.

The simplicity of this process is, however, apparent rather than real when considering the various practical difficulties which are encountered. These difficulties depend upon the high temperature, under which condition the sodium vaporizes and has to be cooled by some suitable method. Such suitable method, however, has not been worked out technically. The chlorine which comes off at the anode being very hot is correspondingly active and the collection and cooling of this material presents difficulties. Also the construction of a containing vessel which will resist the attack of fused salt as well as of the liberated sodium and chlorine, is not a simple matter, and the practical difficulties have defeated many attempts to carry out this process.

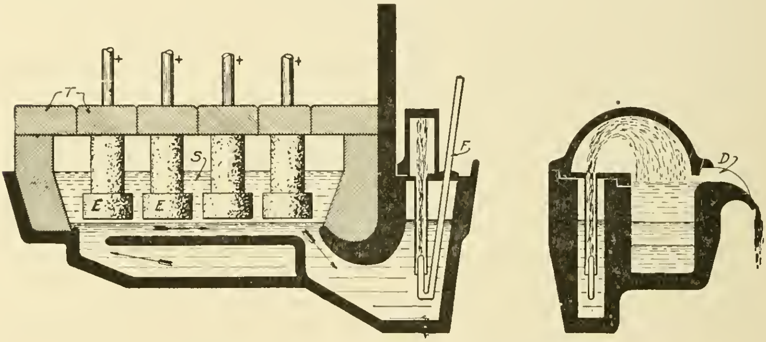
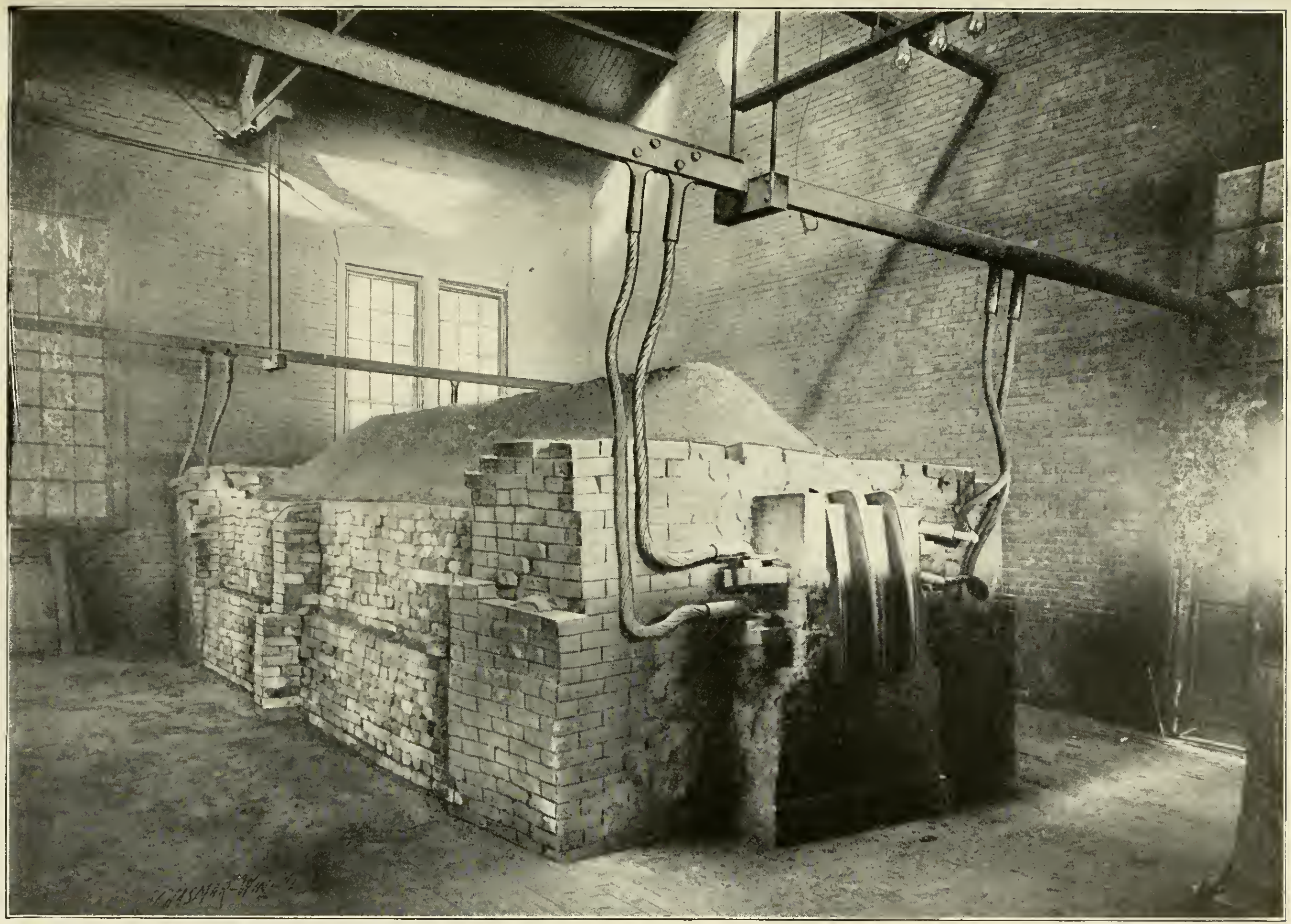


Fig. 18. Sections of Acker's Caustic Soda Furnace
Copied from The Electric Furnace, by Alfred Stansfield

Acker Process. Perhaps the most successful attempt has been the so-called Acker process, which was used for a number of years at Niagara Falls. In this process the fused NaCl was electrolyzed in a cast-iron cell of peculiar construction and lined with magnesia bricks. A cross section of this cell is illustrated in Fig. 18.

The cathode covering the bottom of the cell is fused lead above which rests a 6-inch layer of molten salt *S* and dipping into this are a number of graphite anodes *E* with terminals coming up through the tile roof of the cell *T*.

This process works upon the interesting principle that, when sodium is liberated upon molten lead, it alloys with the lead, forming



AN ELECTRIC FURNACE PREPARED FOR ACTION

Courtesy of The Carborundum Company, Niagara Falls, N. Y.

an amalgam similar to the amalgams of sodium and mercury of the mercury process. To prevent the amalgam becoming too rich in sodium, the sodium is continually extracted from the molten metal by blowing steam through it by pipe *F*, as indicated in the right portion of the diagram. The steam on coming in contact decomposes the sodium to form sodium hydrate, NaOH, and liberates hydrogen. The molten caustic soda thus produced flows out of the cell through at *D*. The reaction between the steam and the amalgam is violent and causes a vigorous circulation of the molten lead.

The chlorine which is liberated in the anode is drawn off from the anode chamber under a slightly reduced pressure by means of a fan. This causes some inflow of air through the crevices in the cover and the gaseous products thus drawn off consist of one volume of chlorine to about ten times the volume of air, the chlorine being then extracted from this mixture by means of lime to form the commercial bleaching powder.

These cells took about 800 amperes at a voltage of about 7 volts, the current efficiency being about 93 per cent.

The anodes were found to have a high durability unless a considerable amount of impurity was in the salt; the presence of sulphates, for example, causes anode corrosion.

The caustic soda produced from this cell is in a fused condition, which on solidifying furnishes a marketable product without the necessity of evaporation involved by the aqueous electrolytic methods.

The high temperature difficulties and the difficulties of cell construction have apparently made it impossible for the fused electrolytic cell to compete commercially with the aqueous methods of sodium chloride decomposition, although future improvements may reverse this condition.

Metallic Sodium. In the manufacture of metallic sodium the electrolytic methods have replaced the older chemical methods and the success has been dependent upon the use of a fused electrolyte which melts at a point much lower than that of salt. The process in most general use is the Castner process, which employs molten caustic soda, NaOH. This is contained in an iron vessel, Fig. 19. In this apparatus there is an extension below the cell for the cathode rod *D* and it becomes sealed by the solidifying of some of the sodium hydrate at G. The cathode may consist of any one of several metals, iron being preferable. A cylindrical nickel anode C surrounds the cathode and between the electrodes is suspended a cylindrical screen of iron gauze. This prevents the sodium globules which are liberated on the cathode from floating over to the anode. The sodium which floats to the surface is ladled out periodically from F through the cover. For successful working, the temperature should be maintained by external heating as low as possible—not more than 20 per cent above the melting point of the material. The somewhat impure material commonly used has a melting point of about 300° C.

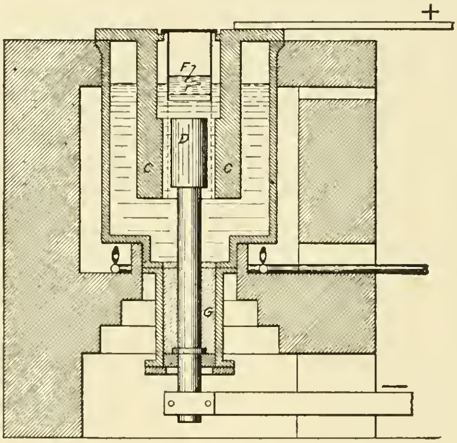


Fig. 19. Castner's Sodium Furnace
Copied from The Electric Furnace, by Alfred Stansfield

A single cell holds about 250 pounds of molten NaOH, takes a current of 1200 amperes at about 5 volts, and works at a current efficiency somewhat less than 50 per cent.

MANUFACTURE OF ALUMINUM

Aluminum is a metal which a half century ago was almost a chemical curiosity but which has now become one of the common and most useful metals in every day service. Although aluminum is one of the most abundant of the elements constituting the earth's crust, it has been locked up so tightly in combination with oxides, silicates, fluorides, and the like, that it has resisted until recently all efforts to isolate it in the metallic state. This has been finally accomplished in a practical way by electrolysis of fused aluminum compounds.

This element is found as an important constituent in most clays, but the known methods of extraction do not yet permit the use of such materials as an aluminum ore. Bauxite, which contains a high per cent of aluminum as hydrated oxide, is used almost exclusively in this industry, but to adapt it to the electric furnace requires, first, a chemical purification to remove such objectionable elements as iron, silicon, and titanium, after which process the material to be treated consists of a pure aluminum oxide, Al_2O_3.

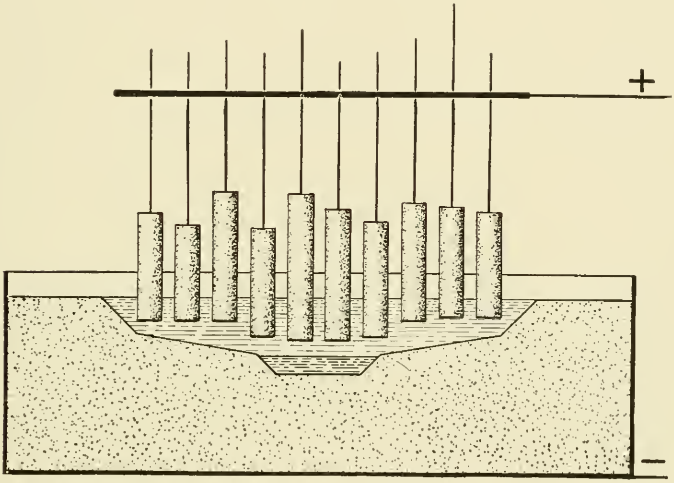


Fig. 20. Aluminum Furnace
Copied from The Electric Furnace, by Alfred Stansfield

The history of the aluminum process is interesting in that it records the almost simultaneous discovery of similar processes in America and in Europe. To Mr. Charles M. Hall is accorded the honor of working out the method commonly used in this country and by which the entire consumption of aluminum in America is supplied.

Hall Process. *Type of Cell.* The typical electrolytic cell, Fig. 20, may consist of an iron box about 6 feet long, 3 feet wide, and 3 feet deep, lined with a thick layer of conductive carbon. This layer prevents the fused material from coming in contact with an iron container and it also acts as the cathode terminal of the cell. The anode consists of a multiplicity of carbon rods 3 inches in diameter, suspended vertically in rows and numbering perhaps 40 to 50.

Solvent for Aluminum Oxide. The important discovery upon which this process is based was in finding a suitable solvent for the aluminum oxide. Such solvent was molten cryolite, being a combination of sodium and aluminum fluorides, represented by formula $3NaF.AlF_3$. Calcium fluoride, CaF_2, is also added on account of its influence on the fusibility. This molten material readily dissolves a certain amount of the aluminum oxide; constituting a true electrolyte which undergoes decomposition upon the passage of the current.

A layer of charcoal is placed on top of the molten bath to protect it from oxidation, and the dry aluminum oxide is fed through this layer to replace that decomposed.

Action of Current. A cell, such as described, takes about 10,000 amperes of current at a pressure of 5.5 volts or upward, depending upon the condition of the bath.

In this cell the current serves a double purpose of heating the bath and keeping it in the proper molten condition for electrolytic decomposition. The aluminum is deposited on the carbon bottom constituting the cathode. At the working temperature the metal is molten and having a greater specific gravity than the electrolyte stays on the bottom. After it has accumulated to a suitable amount, it is tapped off.

At the carbon anodes a corresponding amount of oxygen is liberated and, at the temperature necessary for operation, this oxygen unites with the anode carbon to form carbon monoxide, a gas which on rising upwards burns in contact with the air to CO_2. The consumption of carbon may thus amount to from .5 to .7 of a pound, although on account of the action of the air on the heated carbon anodes and the scrap anodes which are produced, the consumption may run up to about one pound for each pound of material. The current efficiency is reported as being from 70 to 80 per cent. The energy consumption is stated to be about 23,000 kilowatt hours per ton of metal, or stated in other terms, one electrical horsepower a year will produce about one-quarter of a ton of aluminum.

Electrolyte. The electrolyte consists in the main of a number of compounds, chiefly sodium fluoride, aluminum fluoride, and aluminum oxide. It is a well-known fact in electrolysis that that compound in the electrolyte which has the lowest decomposition pressure will be the first one to be decomposed by the current. The following figures show why it is that the aluminum oxide undergoes decomposition rather than the sodium fluoride or the aluminum fluoride:

NaF —4.7 volts, decomposition pressure
AlF_3 —4.0 volts, decomposition pressure
Al_2O_3—2.8 volts, decomposition pressure

If during electrolysis there is an exhaustion of the aluminum oxide, the aluminum or the sodium fluorides may then be decomposed; this also happens to some extent if the current density is run too high.

The increasing demand for aluminum promises to make this industry of increasingly greater importance and this will be accentuated as the price is reduced. A scarcity of suitable ores is becoming felt and increased attention is being given to the extraction of kaolin and other cheaper and abundant materials.

ELECTRIC FURNACE

The use of electrical energy for the production of useful heat is becoming revolutionary not only in the field of metallurgy or technical chemistry where heat is utilized, but also in its effect upon the electric power industry. It is furnishing a load for power stations, or in other words a market for their product. Where heat from electrical energy is used for low temperature operations, such as cooking, drying, soldering, and the like, it is not generally classified as a branch of electrochemistry. When, however, high temperatures are attained, we pass into what is generally considered the field of electrochemistry. There is, however, no sharp line of demarcation as between low temperature and high temperature electric heating.

The device or structure used for transforming electrical into heat energy, where high temperatures are required, is called an electric furnace. The ability of the electric furnace to attain temperatures far beyond those hitherto available by other methods gave it a distinct field of usefulness in which it did not have to compete with existing furnaces. By the use of these temperatures many of nature's most closely guarded secrets have been revealed; a new chemistry of high temperatures has been evolved; new ideas as to the constitution of matter have been developed; new methods of preparing known substances have been formulated; our stores of available materials have been enriched by the discovery of new compounds.

Possibilities at High Temperatures. *All Substances Melt.* In the high temperature produced in the electric furnace it has been shown that all substances can be melted. The oft encountered statement that lime, magnesia, molybdenum, tungsten, and the like, are infusible is therefore incorrect, for not only can all known substances be melted, but they can be volatilized as well. These facts are full of significance and suggestion to the investigator. They show not only that there are limitations upon the materials which he may use for furnace construction, introducing difficulties where the highest temperatures are to be developed, but that it is possible that in the melting and fusion of materials they may undergo such transformation of their physical nature as to endow them with qualities of great value. One of the most successful industrial uses of the electric furnace is the fusion of aluminum oxide in the form of bauxite, resulting in the production of that physical form of the material designated by the trade name "alundum". This is a duplication of Nature's process for producing corundum, but the artificial product has marked advantages over the natural material in purity, cheapness, strength, and toughness, which give it greater value for abrasive purposes.

The fusion of quartz has produced a valuable material for a new kind of glassware which is indestructible by rapid or extreme variations of temperature. Various refractory materials have their refractory qualities increased by melting and subsequent cooling. Experimental investigation in this direction has only begun, but the results already obtained point to many improvements which may be made in materials for furnace construction, materials resistant to chemical corrosion, and materials possessing high heat and electrical insulating properties. The volatilization of elements and compounds at high temperatures gives new methods for the purification and separation of materials, enabling the process of fractional distillation to be applied to all substances.

Behavior of Carbon. It has been shown that carbon is capable of conversion into its various forms, a fact industrially utilized with great advantage by the International Acheson Graphite Company in making graphite and graphitized electrodes from the ordinary forms of coal and coke. Moissan has demonstrated the possibility of changing carbon into the diamond, and has reproduced, artificially, all the varieties of diamonds which Nature furnishes, alike in all respects save size.

All the oxides which had hitherto been regarded as irreducible have been reduced through the use of the electric furnace. Upon experiments which he has made, Borchers based the claim that carbon is capable of taking the oxygen from any known compound at temperatures within the range of the electric furnace. Similarly, other reducing agents may be made effective, and the decomposition can be produced even without any reducing agent whatever by utilizing the electrolytic action of the current. This has resulted in unlocking various of Nature's stores, making available for use such materials as aluminum, magnesium, calcium, sodium, potassium, chromium, silicon, and many others which previously could be obtained only with great difficulty if at all.

Carbides. Moissan's classic researches show us that a large number of elements unite with carbon to form carbides, many of which were not known before the day of the electric furnace. Based upon this fact, though resulting from the independent discovery of the American inventor, Willson, the calcium carbide industry has been developed, and today thousands of tons are being produced annually. The reaction of this carbide with water forms the hydrocarbon, acetylene, which, although now finding its chief use as an illuminant, is capable of being transformed into other hydrocarbons. Manganese carbide reacts with water to form hydrogen and methane; thorium carbide gives ethylene; and cerium and uranium carbides yield liquid and solid hydrocarbons as well as the gaseous ones. Although the hydrocarbons other than acetylene have not been produced commercially, scientifically it is possible to produce petroleum and other like compounds. Such discoveries as these point to the great and significant fact that the whole field of organic chemistry offers itself as an incentive in the exploitation of the electric furnace.

Another class of carbides, such as those of silicon, boron, chromium, molybdenum, tungsten, and titanium, are stable, not only resisting the attack of water but being extremely resistant to the most active chemical agents. The first of these, silicon carbide, or carborundum, has found extensive application as an abrasive, and its use has led to the development of a new industry. Its extreme hardness, approaching that of the diamond, and the refractory nature of it and similar carbides, together with properties which may yet be discovered, point to the probability as well as the possibility that other carbides will have quite as extensive industrial application.

Related Compounds. Moissan and his contemporaries have shown that silicon, boron, and nitrogen, may be made to act like carbon in producing silicides, borides, and nitrides, each new compound having its own peculiar properties, and that the field may also be extended through the manufacture of the more complex compounds, such as the silico-borides, silico-carbides, boro-carbides, etc.

A contemplation of such possibilities is most bewildering, and to quote from an address by Professor Jos. W. Richards referring to electrometallurgical progress, "We are so overwhelmed by new things of possible use to science or industry, that we can at most investigate only a small fraction of them. It is a virgin continent of undeveloped possibilities."

ADVANTAGES OF ELECTRIC FURNACE

The electric furnace owes its place in the scientific and industrial world to certain characteristics which it possesses and to the advantages which it offers over other means of generating heat, the principal one being the high degree of temperature which is made available. An interesting comparison might be worked out showing that civilization progresses in a rate proportional to the utilization of heat energy in its highest degree of concentration. Each additional degree of temperature which can be produced and kept under control shows itself capable of new and useful purposes, and the electric furnace has added such an extension to the range of available temperatures that it has almost doubled that previously available.

Limitations. It simply requires the passage of the electric current through a conducting medium to produce heat, the intensity of which depends upon the amount of current which passes. Inasmuch as most substances retain their conductivity at high temperatures, the degree of intensity which is theoretically possible is unlimited. Practically, however, limitations are placed upon it through the physical difficulties of keeping the conducting medium and the furnace walls in place. The temperature is limited by the fusing point of the material, while it retains its solid condition; when fusion commences, the difficulties of containing the melted material begin, and the temperature is limited by the point of vaporization.

When volatilization begins, the gaseous materials escape from the field of action, carrying away the heat, as rapidly as it is supplied to the furnace, in the form of latent heat of volatilization or energy stored up as potential chemical energy. It is true that the temperature of volatilization might be increased by subjection to high pressure, but this involves the construction of a container which can be made only of solid materials which will not fuse at the higher temperatures.

The electric arc maintained through a carbon vapor furnishes, perhaps, the highest temperature attainable, a temperature which is usually considered definitely fixed by the volatilization of carbon. On account of the limitations of our methods of measuring these high temperatures, the exact value to be assigned to the temperature of the electric arc cannot be stated, though the most satisfactory measurements give values ranging between 3600° and 4000° C. Whether or not this is the ultimate limit to be attained by electrical means is difficult to say. There is, of course, the possibility of exceeding it by maintaining the arc under a high atmospheric pressure, or by feeding electrical energy to the arc more rapidly than it can be dissipated by the volatilization of carbon, or, in other words, superheating the carbon vapor. Such speculation, however, is not necessary to show that the electric furnace has unbounded possibilities, since the range of temperatures below that of the ordinary arc offers an unlimited field for usefulness.

Comparison Between Electrical and Fuel Heating. While the attainment of high temperatures was the first achievement which called attention to the electric furnace and found many technical uses for it, the later developments have been in the direction of using electrical heating in competition with the various metallurgical processes where the combustion of fuel is employed. There are some who doubt the ability of the electric furnace to make inroads upon the fields occupied by other types of furnaces, and maintain heat energy from electricity to be entirely too costly, arguing as follows:

TABLE III

Relative Fuel Costs

Source of Heat	B. t. u. at Cost of One Cent
Coal at $2.50 per ton	112,000 B. t. u.
Natural gas at 20c per M	45,000 B. t. u.
Oil at 4c gallon	32,000 B. t. u.
Producer gas at 4c per M	37,500 B. t. u.
City illuminating gas at $1.00 per M	6,000 B. t. u.
Electrical energy at 10c per kw. hour	340 B. t. u.
Electrical energy at 1c per kw. hour	3,400 B. t. u.
Electrical energy at ¼c per kw. hour	13,600 B. t. u.

Cost of Heat from Fuels. A cheap source of heat energy is coal. On the assumption that one ton of a good grade of coal costs $2.50 and during combustion liberates heat to the extent of 14,000 B. t. u. per pound, the quantity of heat available for one cent will then be 112,000 B. t. u. From producer gas at four cents per thousand cubic feet and containing 150 B. t. u. per cubic foot, the heat attainable for one cent is 37,500 B. t. u. With city illuminating gas, of a calorific value of 700 B. t. u. per cubic foot and costing $1.00 per thousand cubic feet, we have 6000 B. t. u. available at a cost of one cent.

Cost of Heat from Electrical Energy. Electrical energy as distributed for lighting purposes costs in the neighborhood of ten cents per kilowatt hour. When freed from the cost of distribution and if delivered in large quantities without expensive transmission, this energy may be obtained for from one to two cents per kilowatt hour and from waterpower plants it is being sold at even lower prices, two cents per kilowatt hour being near the low limit. One kilowatt hour of electrical energy, when transformed into heat, furnishes about 3400 B. t. u., or, in other words, the heat equivalent of one kilowatt hour is represented by this figure.

Table III gives an idea of the relative cost of heat units obtained by different methods.

From Table III, it is evident that electrical heating with the lowest cost of energy obtainable is over eight times more costly than where heat is obtained from coal. The electric furnace, however, has advantages of such importance that this relative cost of heat units does not constitute a serious handicap for such a furnace. The

TABLE IV

Heat Efficiencies of Furnaces

Kind of Furnace	Efficiency
For generation of steam from coal	50% to 60%
Blast furnace for manufacture of iron	52% to 66%
Open hearth furnace for steel	10% to 12%
Reverberatory furnace	5% to 8%
Crucible steel furnace	2% to 4%
Retort furnace for zinc	2% to 3%
Electric furnace—for graphite	75%
Electric furnace—for fused Al_2O_3	75%
Electric furnace—for iron and steel	50% to 80%

advantages of the electric furnace may be summarized chiefly as follows:

Electrical energy gives "pure, unadulterated heat" to the material which is to be treated, while many of the combustion methods involve the transmission of heat by means of the gaseous products of combustion. The efficiency of electrical heating is, therefore, greater. Table IV gives a numerical idea of the heat efficiencies of various types of industrial furnaces.

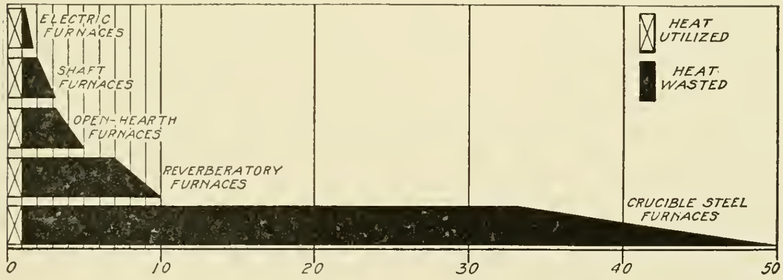


Fig. 21. Losses of Heat in Melting Metals
Copied from The Electric Furnace, by Alfred Stansfield

Fig. 21 gives a graphical representation of the heat lost and utilized in various types of furnaces for melting metals.

The chief reason for the very low efficiencies of combustion furnaces is that the waste products of combustion carry away most of the heat. In a crucible furnace this loss is so great that as much as 98 per cent of the heat energy is wasted. Radiation losses from combustion furnaces are usually greater than for electric furnaces on account of the larger size of the former.

Economy of Electric Heating. As shown in Tables III and IV, 112,000 B. t. u. are available for one cent's worth of coal, but if this heat is used for melting steel in a crucible furnace, only two per cent or 2240 B. t. u. are useful. With electric heating, however, at one-quarter cent per kilowatt hour at an efficiency of 80 per cent, 10,880 B. t. u. are actually available, and the electric heating thus becomes far cheaper even for the lower temperature metallurgical operations.

Added to this advantage of high efficiency, the electric furnace has the merit of making available high temperatures; of making possible a direct application of the heat to the material heated; of making small furnaces do the work of larger furnaces. The volumes of gaseous products which have to be handled are much less with the electric furnace, and this is also important because the gaseous products of combustion frequently interfere with the desired chemical reactions. The electric furnace can be operated with either an oxidizing or reducing atmosphere. Not the least among the advantages of the electric furnace is the more efficient use of refractory materials which is possible. The limitations upon almost all types of furnaces lie in the limitations of refractory materials which are available. In a crucible type of combustion furnace, the heat must pass through the refractory walls to get at the substance to be heated. This means that the heat to pass through this refractory material must have a higher temperature outside than inside. If, for example, iron is to be melted, having a melting temperature of 1500° C., the temperature on the outside of the crucible must be considerably higher than this. On the other hand, if electrical heating can be applied inside of the crucible, the crucible linings may be at a somewhat lower temperature than 1500°.

TYPES OF ELECTRIC FURNACES

While the transformation of electrical energy into heat energy is in itself a simple operation capable of being carried on at an efficiency of one hundred per cent, there are innumerable modifications of furnace construction and operation. Electric furnaces may be classified in two main classes, viz., the arc furnace and the resistance furnace.

Arc Furnace. The electric arc had its first great use for illumination purposes, depending for its usefulness on the fact that an arc maintained between two carbon terminals raises these terminals to such a high temperature as to give off intense luminous radiations. Fig. 22 illustrates such an arc, maintained by the flow of direct current. The arc itself consists of a crater at each of the electrodes and a conductive gaseous medium connecting them, the location of the highest temperature being at the positive crater. This temperature is probably the highest attainable by any known means, being that of the vaporization of carbon.

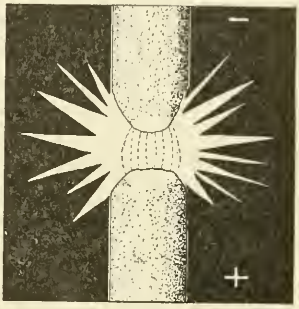


Fig. 22. The Electric Arc
Copied from The Electric Furnace, by Alfred Stansfield

Either direct or alternating current may be used for maintaining an arc and thus we have a subdivision of arc furnaces into the direct-current and the alternating-current types.

In electric furnace terminology, the term electrodes is used in a different sense from that implied in electrolytic cells, being the terminals or conducting bodies furnishing the entrance and exit of the current to and from the furnace. Carbon or graphite is almost universally employed as electrodes for the arc furnace because of the ability of these materials to withstand the intense heat without melting.

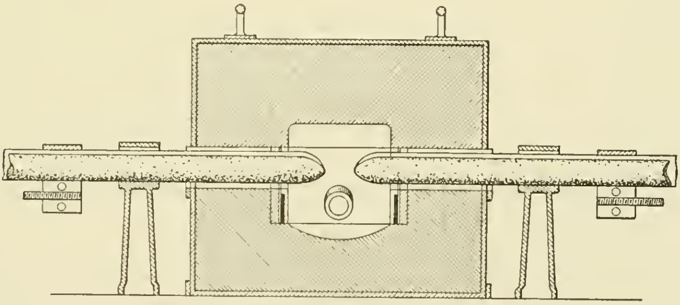


Fig. 23. Small Arc Furnace
Copied from Electric Furnace, by Wilhelm Borchers

The arc furnace differs from the lighting arc mainly in its size and far greater power consumption and in its being enclosed within refractory walls to prevent the escape of the heat. The increased power consumption is brought about by increased flow of current at only slightly higher voltages than those used in the arc lamp. The pressure required to maintain a powerful arc furnace ranges usually between 50 and 100 volts, while the current consumption may be hundreds and even thousands of amperes.

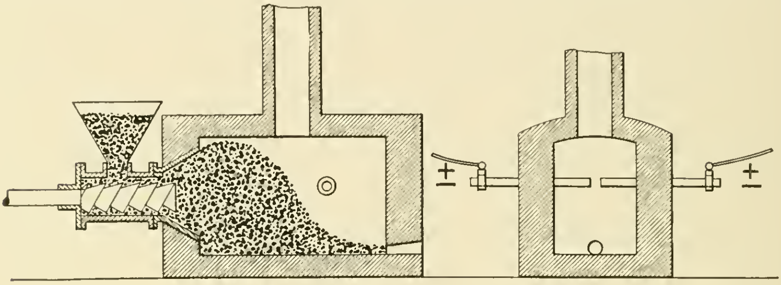


Fig. 24. Sections of an Arc-Muffle Furnace
Copied from Electrothermal and Electrolytic Industries, by Ashcroft

A small arc furnace is illustrated in Fig. 23, where the terminals of two horizontal carbon electrodes are enclosed in an iron box lined with a heavy layer of lime, magnesite, or other highly refractory material. Such a furnace has extensive use in small laboratory operations, where the heat of the arc is radiated from the craters, reflected by the walls, and conducted by the enclosed gases to the crucible or material resting on the bottom of the furnace.

Fig. 24 shows diagrammatically the same type of furnace applied to the treatment of an ore fed continually into the side of the furnace, the volatile products passing up the chimney, and the liquid metal or slag running off at the bottom.

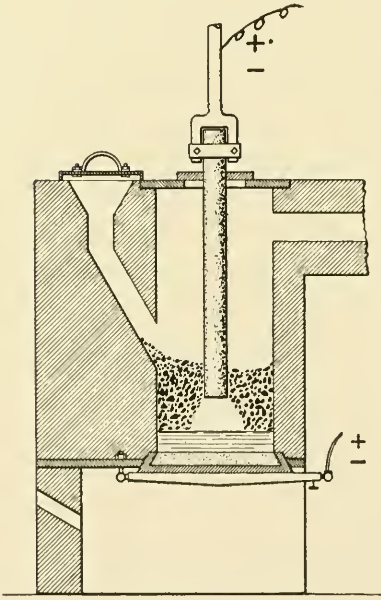


Fig. 25. Furnace with Embedded Arc
Copied from Electrothermal and Electrolytic Industries, by Ashcroft

Another modification is illustrated in Fig. 25, where the arc is actually embedded in the mass of material which is being treated.

In this case the upper electrode consists of carbon and the lower one of the liquid metal or material which is being reduced. In such form of furnace, calcium carbide may be produced, or the reduction of iron oxide may be effected.

An arc furnace in which two arcs are maintained is illustrated in Fig. 26, where *M* represents a mass of molten iron covered by a layer of slag *S*. The current entering one of the carbon electrodes passes through the arc and the slag to the iron, thence through the slag and arc to the other terminal electrode. This is a type of furnace commonly used in the electric steel industry.

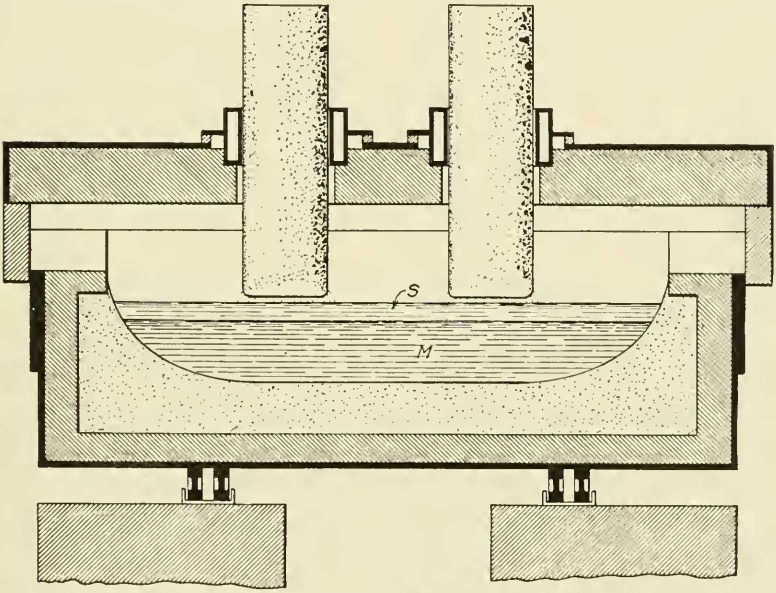


Fig. 26. Furnace with Two Arcs
Copied from The Electric Furnace, by Alfred Stansfield

Resistance Furnaces. The resistance type of furnace depends upon the fact that in passing current through a conductor heat is generated, the temperature being higher the greater the amount of current. Thus heat may be generated within the material under treatment if such material has the proper degree of conductivity. Or the heat may be conducted from the conductive mass carrying the current to a surrounding or adjacent material.

The term "resistor" is used in designating that portion of a resistance furnace which conducts the current and in which the heat is generated. This resistor may be any one of a large variety of materials, such as granulated or crushed carbon or coke, fused metals, slags, or, in fact, any material which is conductive in the liquid or solid state.

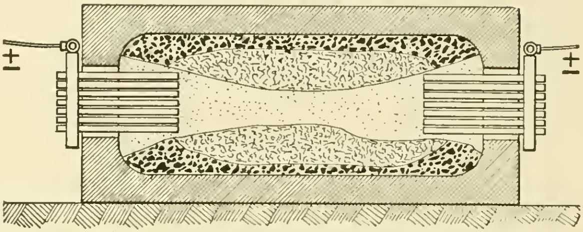


Fig. 27. Resistance Furnace for Graphite and Carborundum
Copied from Electrothermal and Electrolytic Industries, by Ashcroft

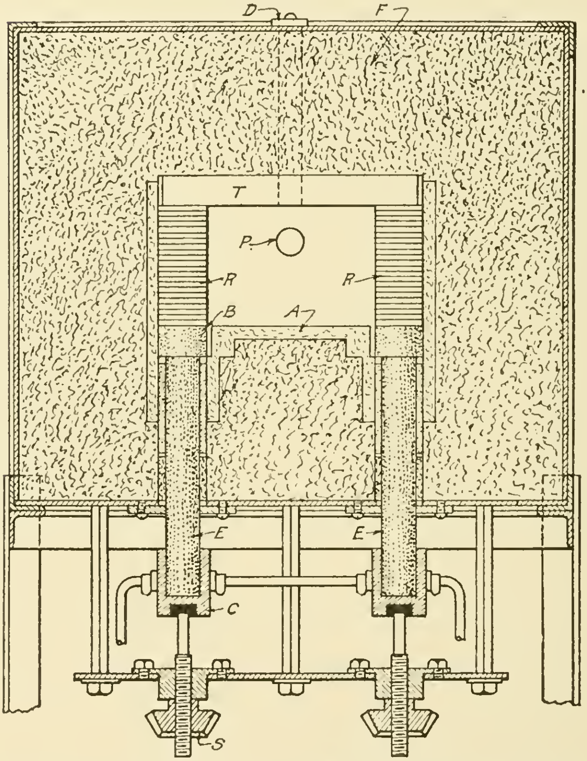
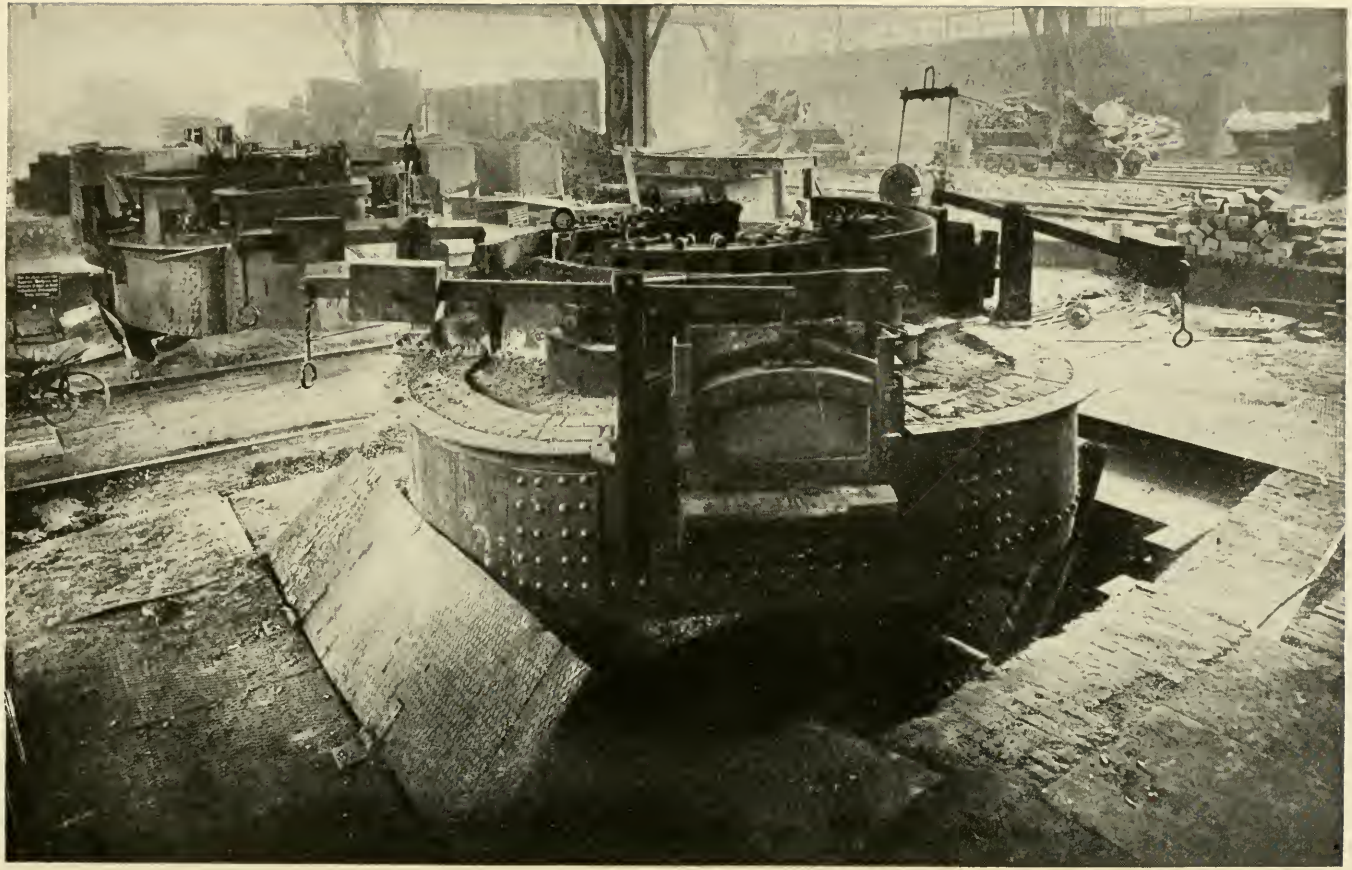


Fig. 28. Section of Muffle Furnace

R—Carbon resistor plates; T—Carbon top plates; B—Graphite bottom plates; E—Graphite electrodes; S—Regulating screws and gears; A—Special refractory cement; F—Fire brick heat insulation; P—Pyrometer hole; D—Draft hole and cover.

Courtesy of Hoskins Manufacturing Company



VIEW OF ROECHLING-RODENHAUSER ELECTRIC FURNACE

This furnace is being used in an iron foundry and is capable of reaching a temperature of 3200° F.

Photograph by Underwood & Underwood, New York

Fig. 27 shows a common type of resistance furnace, such as is used in the manufacture of graphite and carborundum. The resistor is the central column of coke, between the two terminal carbon electrodes, and surrounded by the layers of material under treatment, the whole being enclosed within the retaining walls.

Figs. 28 and 29 show a type of resistance furnace in extensive use for the heat treatment of metals and for other purposes where muffle heating is desirable on a small scale. The sectional view shows two tiers of carbon plates *R*, an upper graphite plate *T*, the carbon plates being pressed upward against this plate by graphite electrodes *E*. The heat is generated by the passage of the current from plate to plate, and the degree of contact is varied by the adjusting wheels at the bottom of the furnace. By this adjustment, and by varying the pressure of the current supplied to the furnace, the desired degree of heat can be attained.

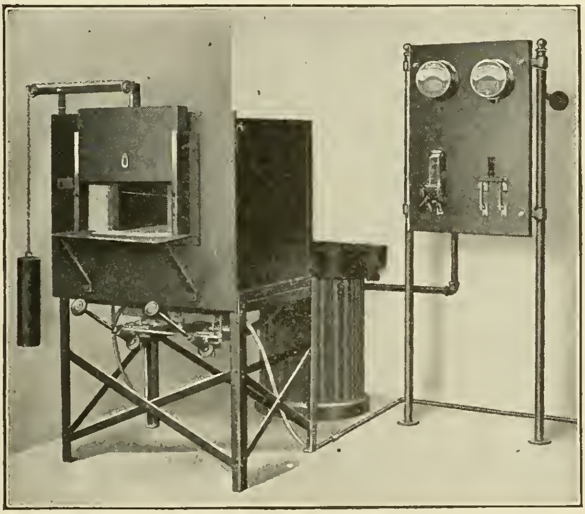


Fig. 29. Hoskins Type F C Electric Furnace
Courtesy of Hoskins Manufacturing Company

COMMERCIAL PROCESSES

NON-METALLIC COMPOUNDS

Calcium Carbide. Lime and carbon mixed together and heated to a high temperature react according to the following equation:

$$CaO+3C=CaC_2+CO$$

That is, the carbon acts as a reducing agent to remove the oxygen from the lime and additional carbon unites with the lime to form calcium carbide.

The temperature required to bring about this reaction is higher than can be furnished practically by combustion furnaces. Electric heating is necessary, therefore, in the production of this compound, and this use has constituted an important electric furnace industry since 1895.

Calcium carbide is a crystalline product which has the property, upon adding water, of liberating gas according to the following reaction:

$$CaC_2+2H_2O=C_2H_2+Ca(OH)_2$$

This gives C_2H_2, or acetylene, which has its most extensive application as an illuminant and it is chiefly for the production of this gas that calcium carbide is manufactured.

The process is a simple one. The raw material consists of an intimate mixture of a good grade of lime and of carbon in the form of charcoal, coke, or anthracite coal.

There are two main types of furnaces used in the treatment; in one type the calcium carbide is removed from the furnace in the form of a solid block; in the other type it is tapped from the furnace in a liquid state.

In the former type, the heating may be effected by means of an arc drawn between two carbon electrodes, the mixture being fed to the heat zone where the reaction takes place and the molten carbide flows into a mass which solidifies in the cooler portion of the furnace. The earlier methods consisted in running a box type of furnace until a certain amount of carbide had accumulated therein, when the current was interrupted and the solidified material removed and broken up for shipment. An improvement in this type consisted in forming the calcium carbide in a rotating type of furnace as illustrated in Fig. 30. The solidified core is rotated away from the arc terminals at a rate proportional to the formation of the carbide. On the opposite side of the furnace, the core is removed by breaking off pieces. This type of furnace is an improvement which insures continuous operation.

In the tapping type of furnace, an iron container lined with a refractory material with a bottom layer of carbon contains the charge. An electrode is lowered from above, and 200 kilowatts and upward of alternating energy is supplied. The higher temperature maintains the carbide in a molten condition and at regular intervals it is tapped from the furnace into iron ladles.

In either the tapping type or the rotating solid core type, continuous operation of the furnace is possible.

The energy consumption per pound of carbide is stated to be in the neighborhood of two kilowatt hours.

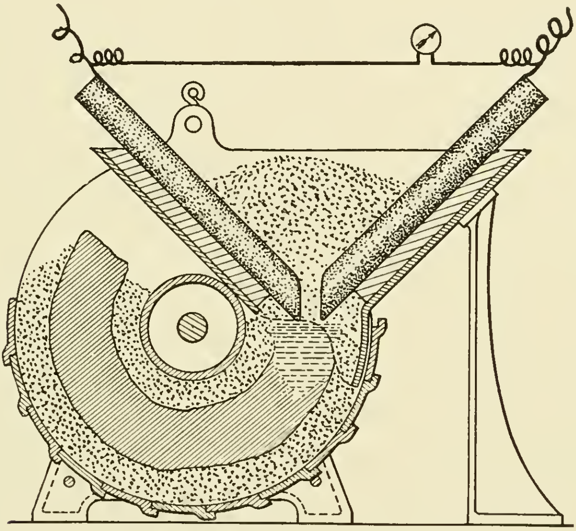


Fig. 30. Rotary Calcium Carbide Furnace
Copied from Electric Furnace, by Wilhelm Borchers

Silicon Products. Just as lime may be acted upon by carbon at high temperatures so reactions likewise take place in mixtures of carbon and silicon oxide or sand. Electric furnace temperatures are the most practical for bringing about these reactions, of which there are several possible ones depending upon the temperature and other working conditions.

One reaction may be represented by the equation

$$SiO_2+C=SiO+CO$$

Silicon monoxide, SiO, is a brown powder. Its suggested uses are as a pigment, as a reducing agent, and as a heat insulating material. Thus far, however, it has been an unimportant technical product.

Another reaction proceeds according to the equation

$$SiO+C=Si+CO$$

That is, the silicon monoxide may be reduced by the carbon to the element silicon with the accompanying evolution of carbon monoxide. Large quantities of silicon have been produced according to this method and a material which was formerly a chemical curiosity is easily produced in large quantities. A construction of furnace which has been proposed for the production of silicon is illustrated in Fig. 31. The electric terminals of the furnace consist of two carbon electrodes introduced horizontally. Connecting these electrodes is a pile of carbon slabs acting as a resistor where the heat is generated. This resistor is surrounded by a mixture of sand and carbon and the molten silicon settles to the bottom and flows through the openings into the lower chambers. This so-called metallic silicon has a purity of about 95 per cent. It is a dense crystalline substance with a dark metallic luster. It has a melting point somewhat less than that of pure iron. Among its uses, it is employed as an addition agent to steel and it is also manufactured into crucibles and containers for resisting acids.

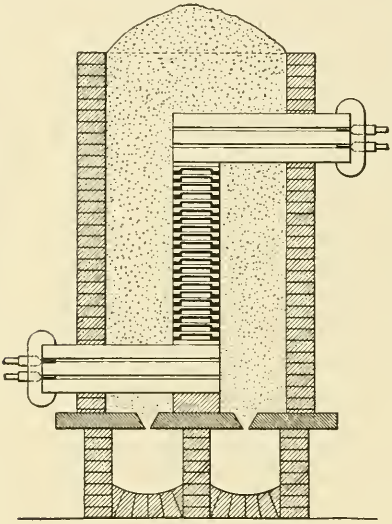


Fig. 31. Silicon Furnace
Courtesy of Electrochemical Industry

Still another reaction which may take place between sand and carbon is represented by the equation

$$SiO_2+3C=SiC+2CO$$

Carborundum. The silicon carbide, SiC, or carborundum, as it is generally known, is the most important of the products obtained from the union of the reactions between silicon and carbon. It was discovered, in 1891, by Acheson, who recognized in the hard iridescent crystal produced a material valuable as an abrasive agent.

The hardness of this material is only slightly less than that of the diamond and it is now produced in large quantities on account of this useful property.

The electric furnace is a simple type of resistor furnace in which a conductive core of carbon about three feet in diameter is placed between the end carbon electrodes which are held stationary in fire-brick walls. Packed around this carbon core is a mixture of finely ground anthracite coal, or coke, with a pure silica sand, mixed approximately according to the chemical formula given above. In addition to these materials some sawdust and salt are added, the purpose of the former being to increase the porosity of the charge and allow the ready escape of the carbon monoxide gas. The presence of salt is claimed to assist in the removal of some of the metallic impurities in a volatile state.

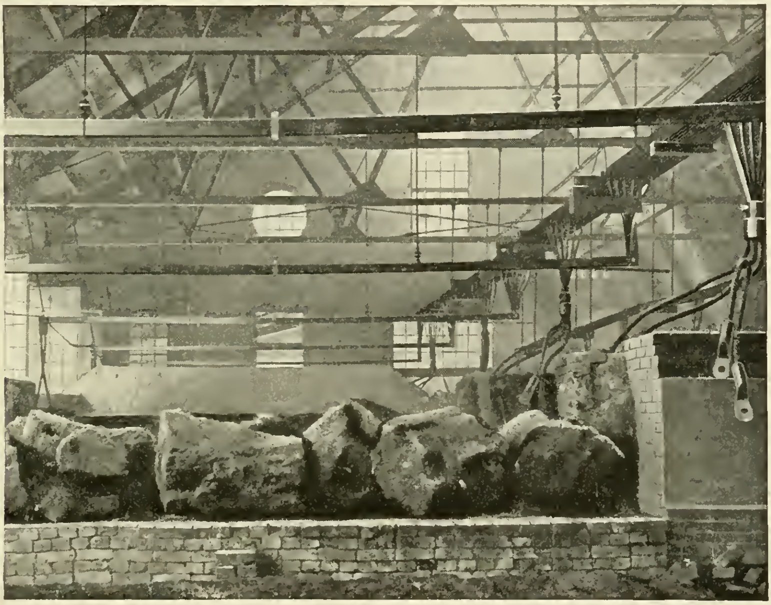


Fig. 32. Carborundum Furnace
Courtesy of The National Magazine

A 2000-h.p. furnace is approximately 30 feet long and takes 6000 amperes at a terminal pressure of about 230 volts. As the core heats up, its resistance decreases so that for a constant power consumption an increased amperage at a lower voltage must be supplied. At the end of the run the current may be 20,000 amperes at a pressure of 75 volts.

When the reaction has been completed, the furnace is allowed to cool down, the side walls are removed, and the carborundum is found as a thick shell around the inner core. Fig. 32 illustrates one of these furnaces in the process of dismantling after a run.

In the operation of carborundum furnaces, considerable quantities of graphite have been produced, especially in the hotter portions of the charge. This is explained by the fact that carborundum when heated to 2200° C. decomposes, the silicon being vaporized away, leaving the carbon in the form of graphite. According to the reaction

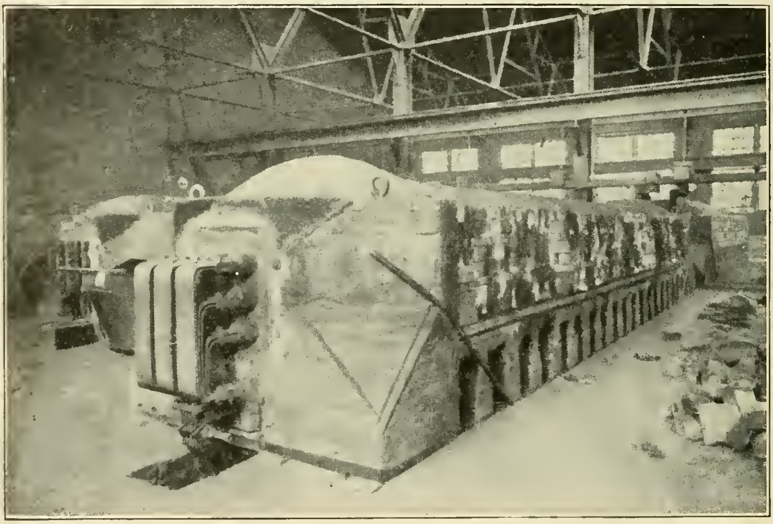


Fig. 33. Graphite Furnace
Courtesy of International Acheson Graphite Company

$$SiC = Si + C$$

Graphite. One of the most spectacular, as well as important, achievements of the electric furnace is the production of artificial graphite. To Mr. Acheson belongs also the credit of its development. He found that at certain high temperatures carbon in the form of coal or coke is transformed into graphite. It has been the prevailing belief that this conversion is brought about through the aid of certain oxides, such as those of silicon, aluminum, and iron. The exact way in which these oxides act is not clear, the supposition being that they act as a catalytic agent. Artificial graphite is now produced in many different grades and the number of its uses is steadily increasing.

The type of furnace for the production of graphite powder is similar to that of the carborundum, having permanent end walls with electrodes, a fire-brick bed, and removable side walls of refractory brick. When charging, a layer of carborundum sand is first placed on the bed to protect it from fusion. The charge is then filled in up to the lower portion of the electrodes. It consists usually of anthracite coal, ground to a varying size. A core of graphitized material is employed on account of its ability to conduct the current and serve as a resistor. Finally more of the charge is placed around and above the core and the furnace is covered with a layer of refractory sand to prevent oxidation.

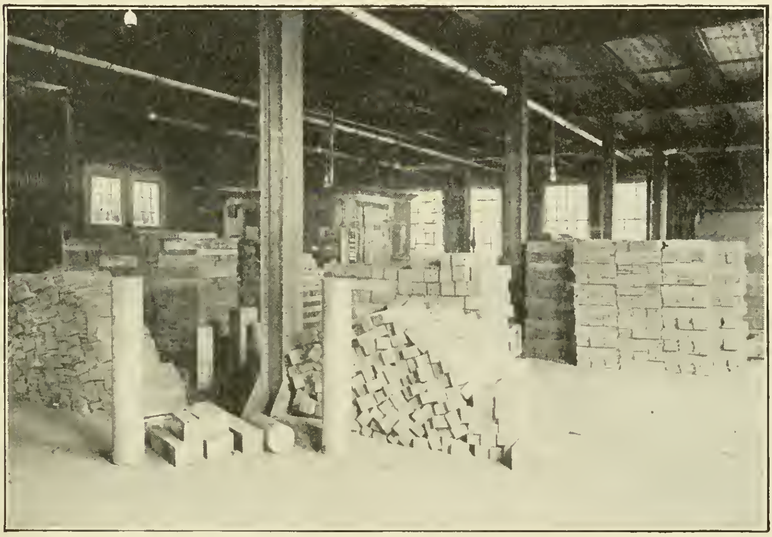


Fig. 34. Graphitized Electrodes
Courtesy of International Acheson Graphite Company

A 1000-h.p. furnace is 30 feet long with a core diameter of 2 feet. The current increases from 3700 amperes to 9000 amperes during heating, while the voltage decreases from the starting value of 200 down to about 80. A run may be 24 hours in length, after which the furnace is cooled sufficiently for dismantling. A graphite furnace in operation is illustrated in Fig. 33.

For the manufacture of graphite in the form of blocks or rods suitable for electrode purposes, a similar type of furnace is used. The ungraphitized articles are made from a mixture of amorphous carbon or finely powdered petroleum coke, pressed and molded with a pitch binder, after which it is calcined in a gas-fired furnace. To convert these carbon bodies into graphite simply means the application of a sufficient amount of heat, to secure which the carbons are packed between the end electrodes of the graphite furnace in a bed of conductive granulated carbon or graphite. The operation is similar to that of the graphite furnace just described.

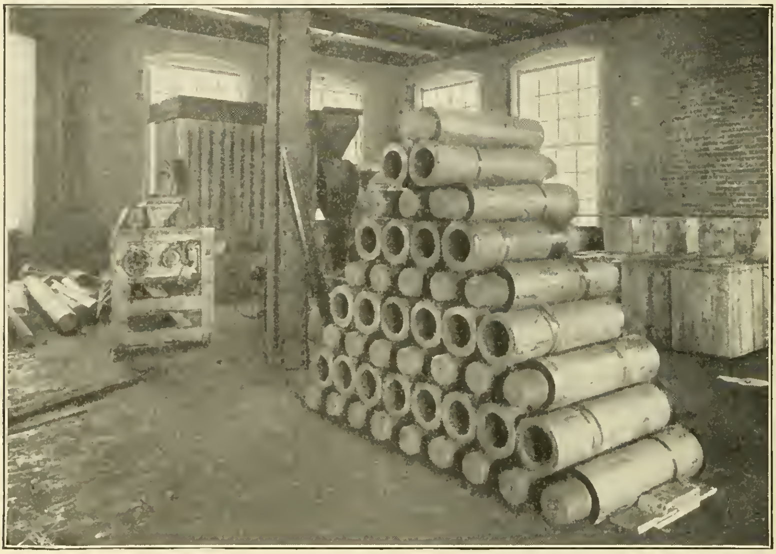


Fig. 35. Graphite Electrodes for Furnace Work
Courtesy of International Acheson Graphite Company

The industry is of interest to the electrochemist not only as being an electrochemical industry in itself but also as furnishing a most valuable form of carbon for electrolytic and electric furnace work. Fig. 34 illustrates various forms of graphite electrodes while

Fig. 35 illustrates large graphitized carbon cylinders arranged to be fitted together for use in electric furnaces.

Alundum. Alundum is another electric furnace product which has a commercial value as an abrasive, also as a highly refractory material. Alundum is the trade name given to fused aluminum oxide. It is made by first purifying bauxite and then fusing it in an electric arc furnace. The furnace consists of a circular hearth of carbon blocks with a removable wall of sheet iron, water-jacketed throughout. Two carbon electrodes introduced from above convey the alternating current to and from the furnace. When a sufficient quantity of the fused material has formed, the solidified material is removed and broken up, crushed, and graded.

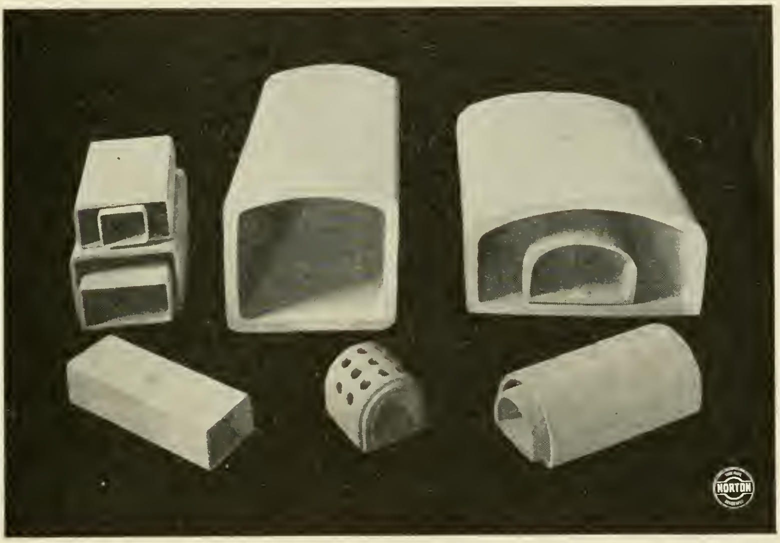


Fig. 36. Alundum Muffles
Courtesy of The Norton Company

From the finely crushed material, grinding wheels are formed, and it is also used in the construction of crucibles and muffles such as illustrated in Fig. 36.

Carbon Bisulphide. One of the big electric furnace achievements is its recently attained monopoly in the production of carbon bisulphide. This is a liquid of the chemical composition of CS_2. The Taylor furnace, by which practically all of the supply of material used in this country is manufactured, is of the resistor type, illustrated in Fig. 37. It is a fire-brick structure, enclosed in a strong iron shell. The resistor consists of pieces of coke or of broken electrode carbons fed into and occupying the space at the bottom of the furnace, and terminal electrodes of carbon supplying the current to this resistor material. The form of carbon used for the resistor does not react readily with sulphur, but the contrary is true of the charcoal which is fed in at the top of the furnace and occupies most of the space in the upright cylinder. The sulphur is introduced into the hearth of the furnace below the electrodes, where it is vaporized and passes upward through the charcoal where the reaction takes place. The carbon bisulphide vapors leave the furnace at a comparatively low temperature.

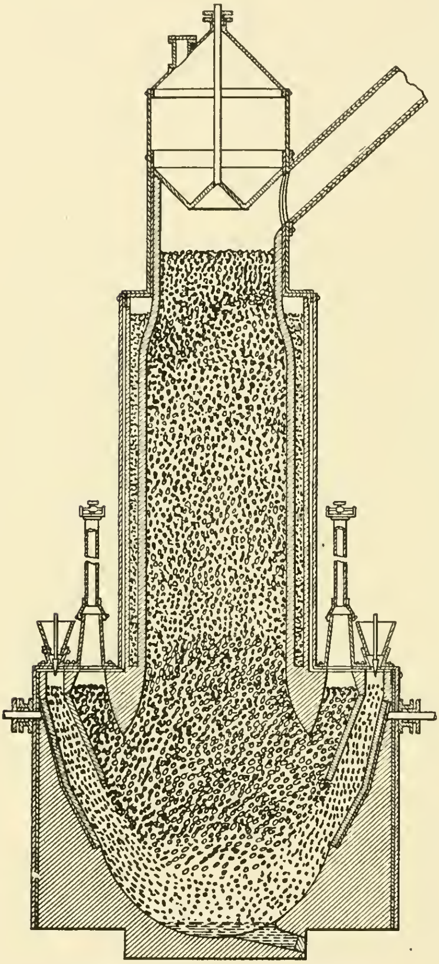


Fig. 37. Carbon Bisulphide Furnace
Copied from Production of Carbon Bisulphide, by Taylor

ELECTRIC FURNACES IN THE STEEL INDUSTRY

After years of experimental and exploitation work, the electric furnace has reached a position of commercial importance in the iron and steel industry. While at present a comparatively small tonnage of steel is influenced by electric furnace development, there is a general prediction that the electric furnace is going to become of great importance.

The different ways in which the electric furnace may be used in this industry may be classified as follows:

(1) The direct reduction of iron from its ores, producing either a pig iron or finished steel.
(2) Replacing or supplementing the existing types of metallurgical furnaces for the manufacture of steel from pig iron.
(3) The replacement of the crucible process by the electric furnace.
(4) For the heating of billets and bars, for the purpose of heat treatment or for rolling and drawing purposes.

Direct Reduction of Iron from Its Ores. For this purpose the electric furnace must replace the ordinary blast furnace in which the iron ore is reduced by being mixed with coke or other form of carbon, the heat for reduction being supplied by the combustion of the fuel. This type of furnace has a high thermal efficiency, being above 50 per cent, and from the standpoint of cost of energy, the electric furnace has little opportunity for competing. The electric furnace, however, supplies heat by the transformation of electrical energy, while the heat from the blast furnace must be obtained from the combustion of the carbon in the furnace charge. Therefore, with the electric method a material saving can be made in the amount of coke or other form of carbon used, and this method is therefore advantageous where fuel is scarce and waterpower plentiful. Furthermore, a higher temperature can be obtained by the electrical method of heating so that certain refractory ores can be reduced in the electric furnace which would clog up the ordinary blast furnace.

For the successful direct smelting of iron ores there is required a very cheap source of electric power in a location where there is a market for the product, also a convenient source of iron ore, and where a saving in the amount of carbon used is of importance; in other words, where the price of coke or charcoal is high. These conditions are found in only a few places, such as along the Pacific Coast, where extensive experiments along this line have been carried out. In the industrial centers, however, the direct reduction of iron ores does not seem to be practicable by the electrical method.

Manufacture of Steel from Pig Iron. Steel is commonly made from pig iron by taking the molten iron as it comes from the blast furnace and putting it through a refining operation, in the Bessemer or open hearth, or other similar refining process. If the refining is not done in conjunction with the smelting operation, the pig iron is shipped to the place where the refining plant is installed, and in this case the pig iron must first be melted up.

It is evident that there are various ways in which the electric furnace may be employed, either to replace or to supplement the ordinary refining operations. Instead of running the molten pig iron into the Bessemer converter, the hot metal may be run into an electric furnace and the refining operation carried on by the addition of the electrical heat which may raise the charge to any desired temperature. On the other hand, the electric furnace may be used only as a finishing step after a certain amount of refining has been done by the ordinary process.

Temperature is an important factor in the refining operation, and under the higher temperatures available in the electric furnace, the refining may be carried out more quickly and to a higher degree than is possible by the fuel methods of heating. For such purpose the electric heating has a high thermal efficiency as against the much lower thermal efficiency of the gas- or fuel-heated furnace; and in taking the molten material from the blast furnace or melting furnace, heated by fuels, the electric furnace is called upon only to do the high temperature, or critical, part of the work. It is claimed that by its use a specially high quality of steel may be secured and that the uniformity of the product is much greater than is otherwise attainable.

Manufacture of Crucible Steel. In the manufacture of high grade tool steel, the electric furnace seems to have its most marked field of usefulness.

The crucible process, as ordinarily carried out, consists in melting up in graphite or plumbago crucibles a commercial grade of pure iron and adding the purifying and alloying agents which are required. The crucibles, costing about $2.50 each, will hold about 100 pounds of metal and can be used six or seven times. These crucibles are heated by the products of combustion and the thermal efficiency is very low, being in the neighborhood of two per cent. The electric furnace with its 80 per cent efficiency is, therefore, able to compete profitably, and the high cost of crucible maintenance gives the electric furnace another opportunity to win out in the struggle for supremacy.

Arc Type of Furnace for Iron and Steel. The various forms of the arc type of furnace are playing the more important part in the electrometallurgy of iron. As illustrative of the leading forms of arc furnace, reference may be made to Fig. 38, showing the Stassano, the Heroult, and the Girod methods of operation.

Stassano Furnace. This furnace in practice assumes several forms. It consists of a thick walled, rectangular chamber with a slightly arched roof. The electrodes are introduced into the side of the furnace and the raw material charged in at the ends. Tapping holes are provided for the slag and the finished steel. Another modification takes a circular form in which the entire furnace is slightly inclined and rotated slowly about its axis so as to give some agitation to the furnace contents. The fixed type of furnace has been designed up to a capacity of 750 kw., while the rotating furnace has a capacity of about 200 kw. This furnace operates at a pressure of about 150 volts, somewhat higher than is usual with arc furnaces on account of the long arc which is employed.

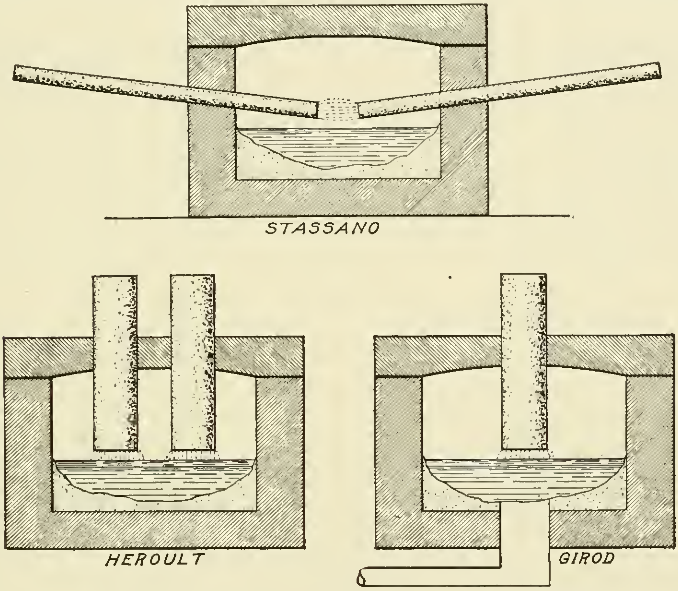


Fig. 38. Sections of Three Representative Types of Steel Furnaces

Heroult Furnace. This furnace, which appears to be most widely used in this country, is of a simple construction consisting of a shallow hearth lined with refractory material and roofed over with silica brick. The contents are discharged by tilting the entire furnace, together with the electrode supports. Two electrodes enter

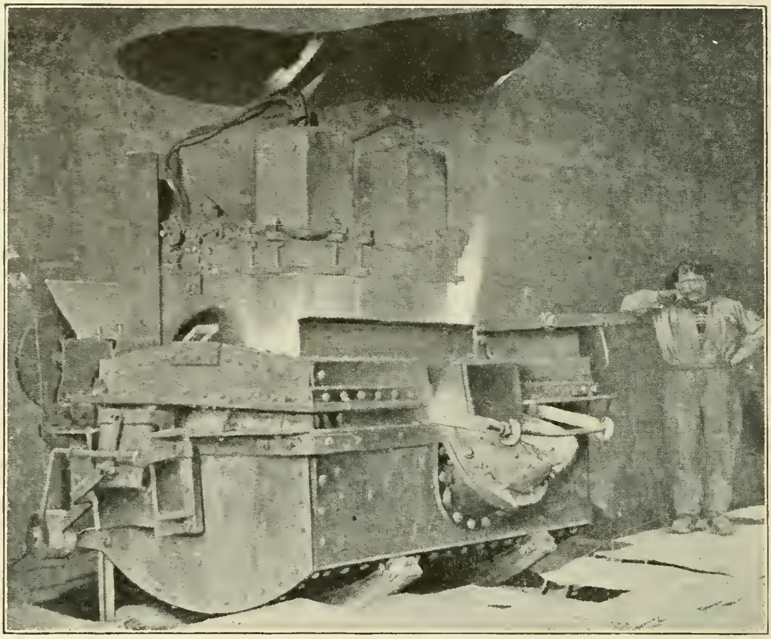


Fig. 39. Heroult Furnace in Operation
Courtesy of Société Electro-Métallurgique Française

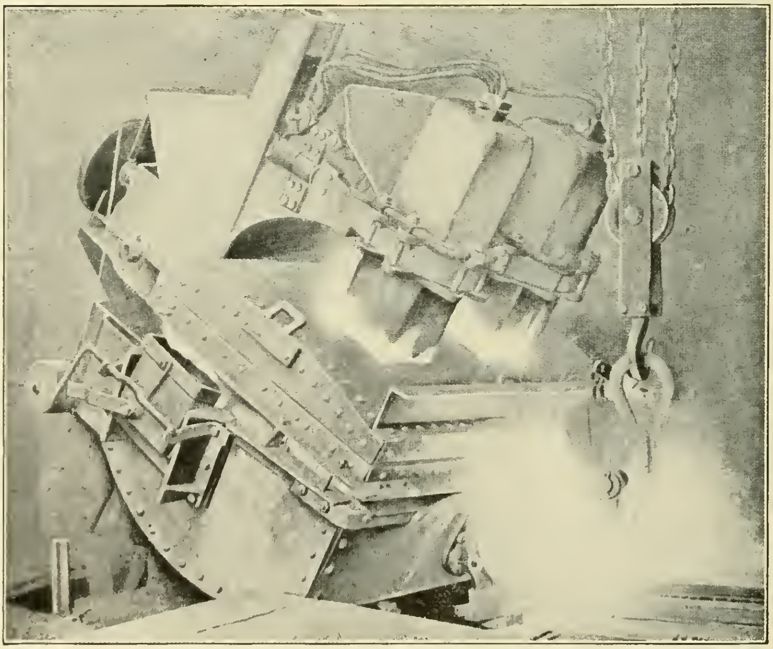


Fig. 40. Heroult Furnace Discharging Molten Steel
Courtesy of Société Electro-Métallurgique Française

vertically through openings in the roof and project down to within one or two inches of the surface of the bath. They may be water cooled at the points where they pass through the roof as well as at the cable connections. Furnaces of a capacity of from 15 to 20 tons have been used and operated at pressures of from 45 volts to 100 volts, depending upon the energy input. A 15-ton furnace requires

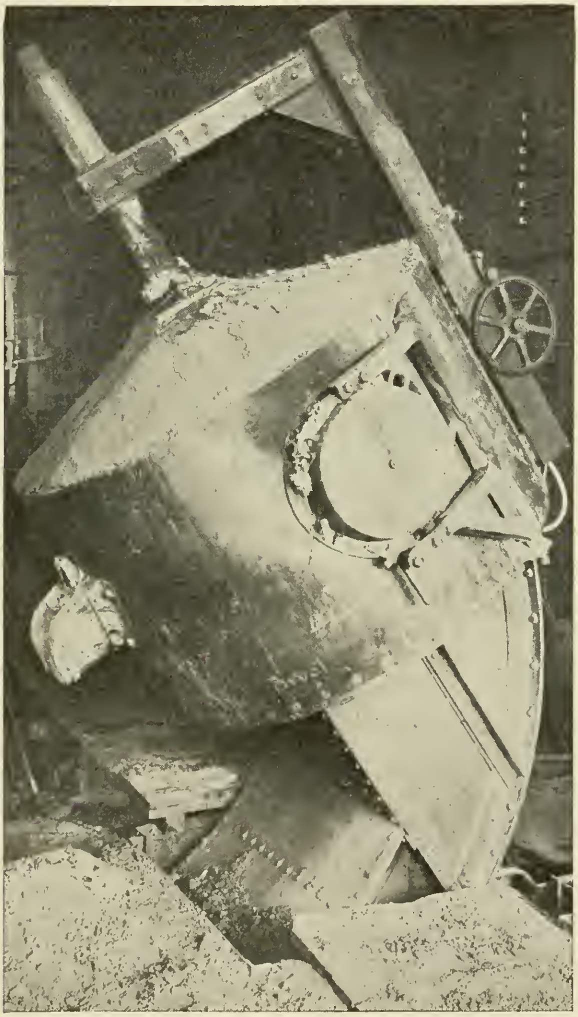


Fig. 41. Steel Furnace About to Pour Its Charge
Courtesy of The Iron Age

up to 2000 kw. Fig. 39 illustrates the Heroult type of furnace in operation, while Fig. 40 shows the tilting operation for discharging the finished product.

Girod Furnace. This furnace differs from the Heroult in that the current enters through the electrode in the roof of the furnace, Fig. 41, arcs across to the slag, then through the steel bath, finally leaving by one or more steel electrodes embedded in the refractory hearth material. Thus instead of having two arcs in series there is only one. The voltage of this furnace is, therefore, approximately half that of the Heroult type and with furnaces of equal load the current is necessarily twice as great. These furnaces have been built up to capacities of 15 tons. The voltage varies between 55 and 75 volts and a 300-kw. furnace will take from 5000 to 5500 amperes and a 1200-kw. unit will take 20,000 amperes.

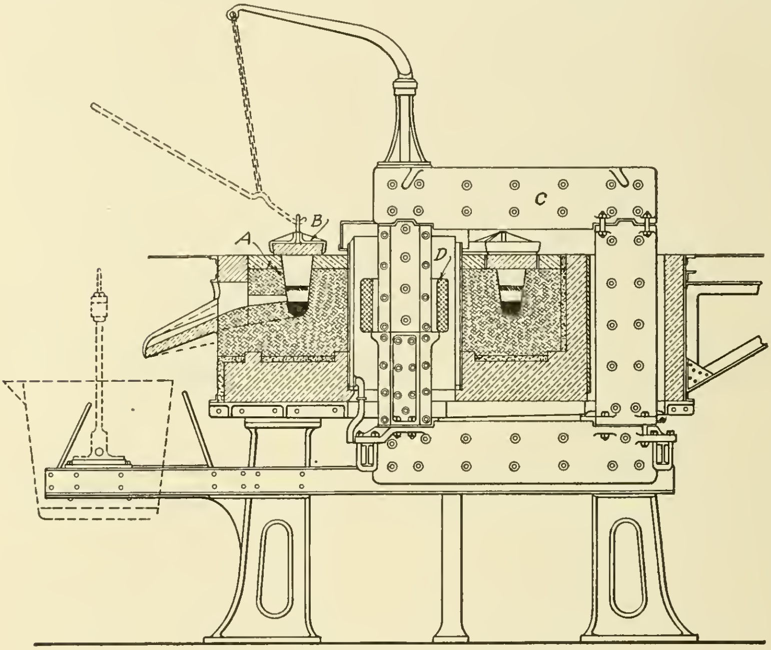


Fig. 42. Cross Section of an Induction Furnace
Courtesy of American Electric Furnace Company

Induction Steel Furnaces. An important type of steel furnace is what is known as the induction type, whereby the use of electrodes is entirely avoided, as is also the contamination of the steel by pieces of carbon breaking off from the electrodes. The absence of carbon electrodes is made possible by causing the molten metal, in a continuous circuit, to carry the energy which is applied to it by magnetic induction. In other words, an induction furnace is a step-down transformer with a short circuited secondary consisting of a single turn of the molten metal. It is obvious that the molten metal must be confined in a channel surrounding the core of the transformer, which core is also wound with a winding of a suitable number of turns to correspond with the alternating voltage which is applied.

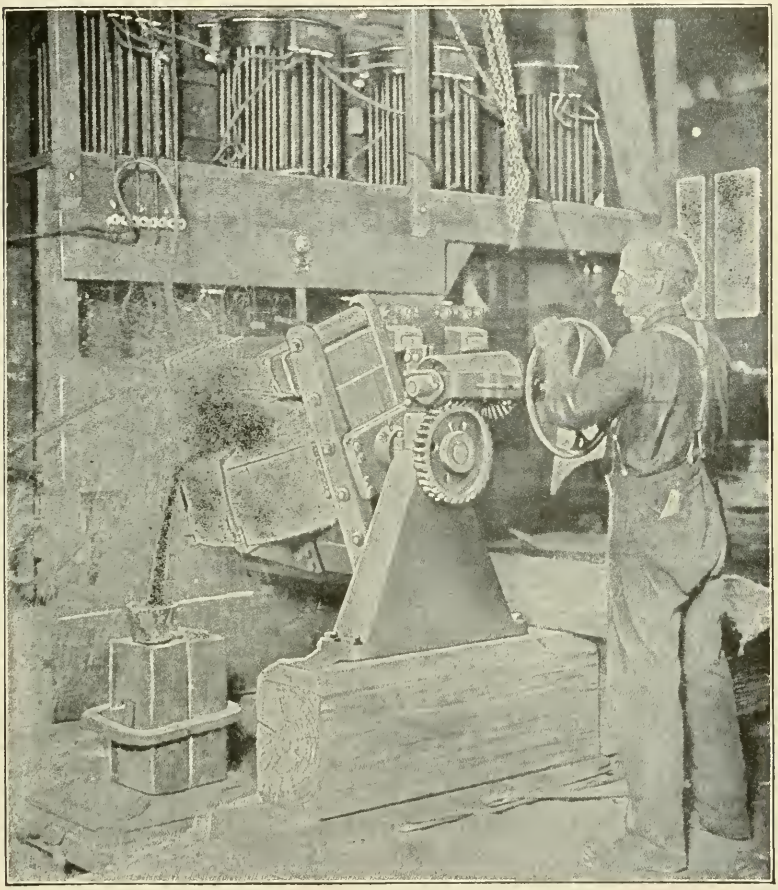


Fig. 43. Induction Furnace in Operation
Courtesy of American Electric Furnace Company

Fig. 42 shows the cross section of an induction furnace, *C* representing the iron core, or transformer, *D* the winding placed thereon, *A* the molten metal constituting the single turn secondary embedded in a refractory channel, and *B* the refractory cover for this channel.

To get such a furnace in operation, it is necessary that there be a continual metal mass, which is afforded by pouring molten metal into the furnace. When a pour is made from the furnace, care is taken to retain some of the metal to act as a starter for the next run.

As counterbalancing the obvious advantages, this furnace has losses and disadvantages which have restricted its general use. It is subject to magnetic and electrical losses due to hysteresis in the iron core, heat losses in the primary circuit, and magnetic leakage. Furthermore, there is a large heat radiating surface by reason of the long channel which must be employed for a given quantity of metal. Fig. 43 shows the operation of a small induction type of furnace.

ELECTRICAL DISCHARGE IN GASES

Thus far consideration has been given to the use of currents passing through solid or liquid conducting materials where comparatively low voltages are required; also to a certain vapor type of conduction in the low voltage electric arc.

Characteristics of Discharge. A new and rapidly developing field of applied electrochemistry utilizes phenomena attendant upon the application of high voltages to gaseous media. Fig. 44 conveys diagrammatically an idea of the relation of current and voltage when an increasing difference of potential is applied to two similar electrodes separated by air or other gas. As the voltage is increased from zero, there is little flow of current or, in other words, the electrodes are practically insulated. By sufficiently sensitive instruments a slight flow of current may be detected, as indicated by the portion of the curve marked "non-luminous discharge". This produces no physical or chemical effects and is unimportant from the practical standpoint. Upon reaching a certain voltage, however, there is a discontinuity of the curve, the current increases, and the discharge between the electrodes becomes luminous. The appearance and exact nature of this luminous discharge vary, being dependent upon whether direct or alternating currents are flowing, the shape of the electrodes, and various other factors. It is designated as a glow or brush discharge. The intensity becomes greater as the voltage increases, and when air is a medium, the oxygen is conveyed into ozone.

The current for the brush discharge becomes a maximum at a certain voltage, indicated by the highest point on the curve, after which there is a more rapid increase in current, and a marked lowering of the voltage is necessary in order to keep the discharge under control. The discharge then assumes the form of the high tension arc. The sparking is very pronounced and the discharge is active in producing nitric oxide from the air. The fact that the voltage falls is due to the increased conductivity of the gaseous medium caused, in turn, by the higher temperature produced by the increased current. This form of arc has important technical uses which will be illustrated later.

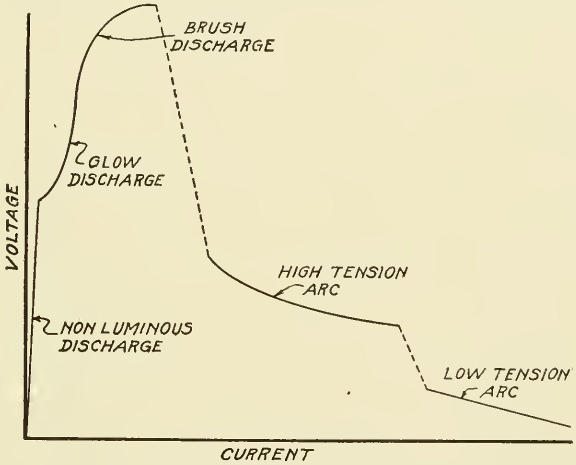


Fig. 44. Curve Showing Relation of Current and Voltage with Increasing Potential at the Terminals

If the current of the high tension arc is allowed to increase, a point is reached where the low tension arc is produced. This is a form of arc which has been previously considered in connection with arc lights and the arc furnace.

PRODUCTION OF OZONE

Ozone is a polymerized form of oxygen. It has a molecular formula of O_3 instead of O_2, the symbol for oxygen. In other words, a molecule has three atoms of oxygen instead of two. It has a powerful oxidizing property which makes it highly useful for bleaching, disinfecting, oxidizing oils, etc. Its most extensive use is for water purification.

Ozone from Oxygen. Oxygen can be converted into ozone by heating to a very high temperature and then suddenly cooling, but only small yields are produced by this method. The use of the silent electric discharge at room temperatures avoids this difficulty.

Siemens-Halske Ozonizer. A great number of forms of technical ozonizers have been proposed. The Siemens-Halske apparatus, indicated in Fig. 45, is an important type of commercial apparatus used in water-purification plants. It consists of an iron container provided with glass windows. Passing upward through the container are a number of vertical glass cylinders coated outside with a metal which serves as one electrode. In the center of these tubes are placed the other electrodes consisting of cylinders of aluminum foil. Water is run through the container outside of the tubes to keep the apparatus cool and keep up the efficiency. The air is previously dried by means of calcium chloride or some other suitable drying agent and passes along the annular spaces between the electrodes. The metal outside of the tubes is connected to one terminal of a high alternating pressure and the inner electrodes are

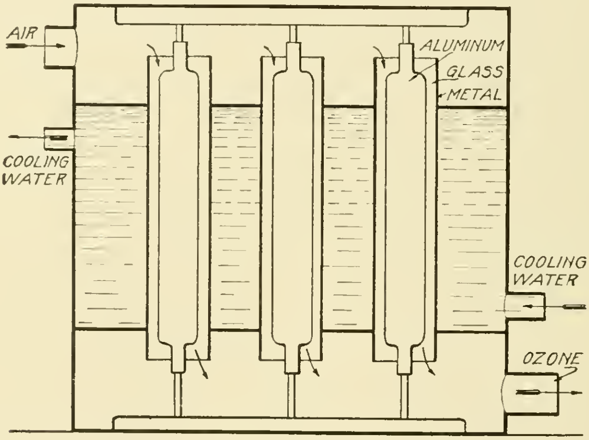


Fig. 45. Section of Siemens and Halske Ozonizer

connected to the other terminal. The iron container is connected to earth, thus preventing a risk to the operator.

A pressure of from 4000 to 7000 volts has been used on this type of ozonizer, and plants for water purification have been operated in Paris and St. Petersburg.

By placing the apparatus in a darkened room it is possible to tell from the luminous appearance whether it is working properly. It is claimed that with an expenditure of 57 kilowatt hours, a million gallons of water may be sterilized by this means. The method of sterilization consists in compressing the ozonized air and forcing it up through towers down which the water is passing.

FIXATION OF NITROGEN*

The most important use of the high tension electric arc is in the so-called fixation of atmospheric nitrogen.

Nitrogen for Fertilizers. Nitrogen is the most important element which gives value to our principal fertilizers. The increasing demand for such fertilizers and the approaching exhaustion of the great deposits of sodium nitrate and other natural nitrogen compounds make the problem of the future supply of great importance. The atmosphere contains a free and inexhaustible supply of this element, but in this form it is not directly useful because it is not "fixed", that is, in combination with other elements which appear to be essential for its usefulness in the growing of crops.

It has long been known that where a high tension discharge takes place, there is a partial union of the oxygen and nitrogen of the air to form the chemical compound NO.

Following the design and operation of a great many types of apparatus, it was found advisable to avoid short thick arcs and to employ long thin stable arcs which would come in contact with a large quantity of air. Units of large capacity in consuming much energy have been worked out.

Birkeland=Eyde Process. An electric furnace devised by Birkeland and Eyde has achieved a notable success in the fixation of nitrogen of the air. In this furnace a large surface of contact of air and arc is attained. The principle is illustrated in Fig. 46. Two water-cooled copper electrodes are brought within a distance of one inch or less and are connected through an inductive resistance to a source of alternating pressure of 5000 volts. The high tension arc which is first produced quickly breaks down to a low voltage arc carrying a heavy current. This low voltage arc is avoided by an ingenious method of placing the poles of a powerful electromagnet at either side of the arc, Fig. 47. It is well known that a conductor located in a magnetic field and carrying a current tends to move out of that field. The electric arc follows this law and tends to move upward or downward, depending upon the direction of the current. In moving away from the straight line connecting the two ends of the electrodes, it becomes lengthened and this lengthening tends to maintain the arc as a high tension arc and avoids the low tension form. In moving away and lengthening, the resistance increases, the current falls off, but the voltage increases because of the

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* An exhaustive treatise on the utilization of atmospheric nitrogen is published by the Department of Commerce and Labor, under the authorship of Thomas H. Norton.

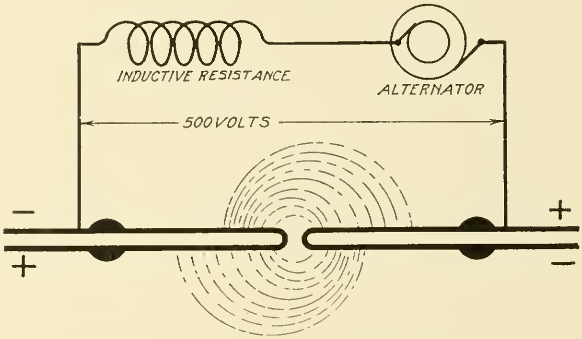

Fig. 46. Diagram of the Electric Circuit in the Birkeland-Eyde Electric Furnace

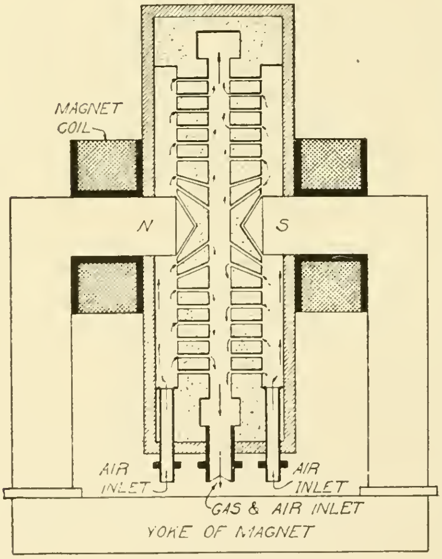

Fig. 47. Birkeland-Eyde Furnace

lower voltage drop through the inductive resistance. The arc is finally drawn to such a length that it breaks and a new arc is then established and goes through the same process. By using an alternating current, the arc formed by one-half of the alternating-current wave travels upward from the electrode and on the reversal of the current an arc is formed which travels downward, and these arcs are formed at the rate of fifty per second, in accordance with the frequency of the current used. On account of this high frequency it is impossible to detect each separate arc and in looking into the furnace what is seen is apparently a large disk sheet of light. The air is introduced so that it travels parallel with this disk and is, therefore, fully exposed to the action of the discharge.

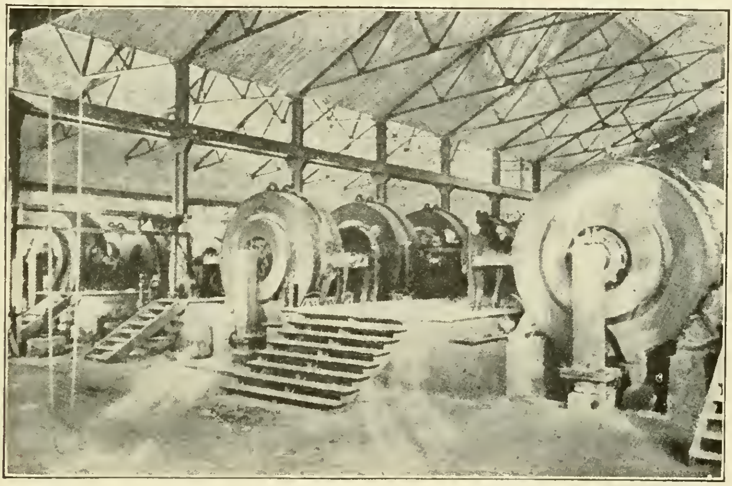

Fig. 48. Birkeland-Eyde Furnaces at Notodden

It is estimated that the temperature of the disk is about 2300° C. The furnace is of steel, lined with fire-bricks which are perforated by holes through which the air enters.

Units of 750 kw. have been employed, such units requiring a pressure of 5000 volts. The full sized units in operation are illustrated in Fig. 48.

ELECTRICAL FUME PRECIPITATION

Another important application of high tension currents is in the removal of suspended particles of solid or liquid materials from

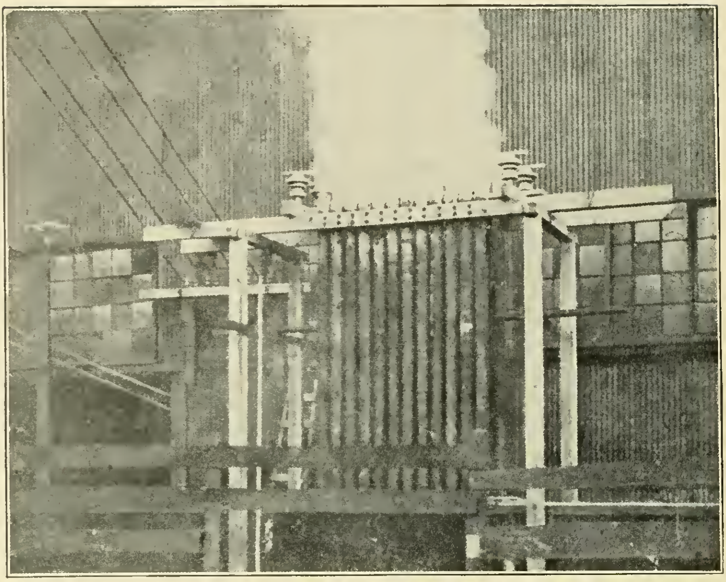

Fig. 49. Experimental Tubular Treater Before Application of Current. Fumes in the Center Above Apparatus

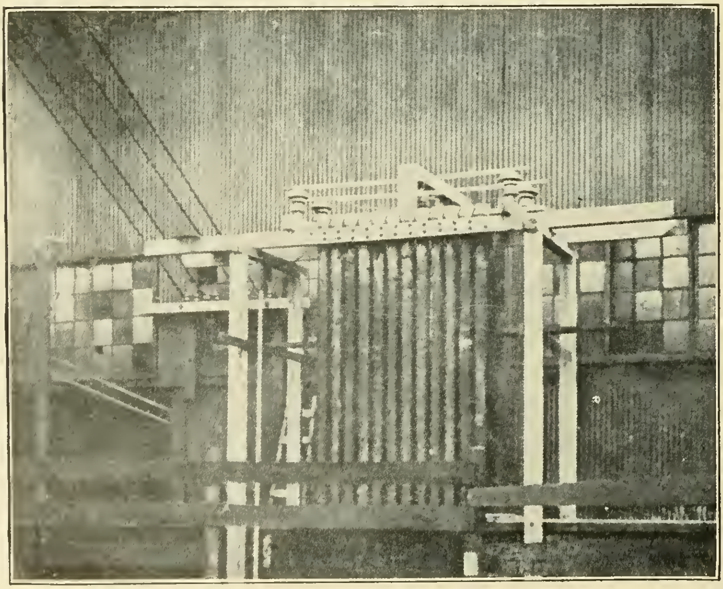

Fig. 50. Tubular Treater After Current Has Been Turned On, Showing Dissipation of Fumes

gases. It has long been known that the fine particles constituting fog, dust, and fume, may be quickly settled by passing between two electrodes at which a high pressure is maintained. There is an agglomerating effect on the suspended particles which causes them to produce larger bodies which settle by gravity. When direct pressures are employed, there is an actual attraction between the electrodes and the agglomerated particles, which increases the rate of settling or collection.

Recovery of Valuable Products of Combustion. This phenomenon has a commercial application in the settling of valuable materials which are carried in furnace gases, not only to render these gases less objectionable to the surrounding territory, but also to recover valuable materials which would otherwise be lost. It also looks promising in connection with the smoke problem. There are likewise innumerable instances in industrial work where the separation of solid and liquid particles from the air can be advantageously effected by this method.

Cottrell Process. The commercial practicability of this action of high tension currents has been demonstrated recently in the work of Dr. Cottrell and the United States Bureau of Mines. In the apparatus used, an economic and effective source of high tension direct current is obtained by transforming the ordinary alternating current up to 20,000 to 30,000 volts and then rectifying this pressure to an intermittent direct current by means of a rotary contact maker, driven by a synchronous motor. This high tension direct current is applied to a system of electrodes in the flue, which carries the gases to be treated. Numerous practical forms and arrangements of electrodes have been developed to meet the exacting and varied conditions of large scale operation in different installations.

The effect of turning on the current to an experimental apparatus used in connection with a copper converter is shown in Figs. 49 and 50.

REVIEW QUESTIONS

REVIEW QUESTIONS

ON THE SUBJECT OF

POWER STATIONS.

---

1. Why is it desirable to allow a reserve capacity when deciding upon the number of units to be installed?

2. Draw a diagram of the piping system for what you consider a first-class arrangement of the units.

3. Would you use a high or low-speed engine (*a*) in the case of a 200 K.W. generator; (*b*) in the case of a 300 K.W. generator; (*c*) in the case of a 1,000 K.W. generator?

4. When alternators are driven in parallel by gas engines, what arrangement is used to compensate for the variation in angular velocity?

5. Is it better to have a machine of very high efficiency at the expense of excessive cost, or to have it reasonable in price with lower efficiency?

6. What arrangement is now frequently used to avoid placing the different pieces of apparatus directly on the panels of a switchboard?

7. Explain the function of a substation and tell of what its equipment should consist.

8. What are the advantages of oil switches?

9. Explain why the capacity of a 6-phase rotary converter is greater than that of a single-phase, two-phase, or three-phase.

10. Which system of charging for power do you consider the fairest and best? Explain why.

11. Explain what is meant by a reverse-current relay, and give an example of its usefulness.

12. What factors must be taken into consideration when locating a rotary converter substation?

REVIEW QUESTIONS

ON THE SUBJECT OF

SWITCHBOARDS

1. What is the object of a switchboard and of what does it consist?
2. What are the most essential points to be considered in designing a switchboard?
3. How are switchboards divided as to their mechanical features?
4. What advantages has a pipe framework?
5. Give a wiring diagram for a small generator equipment.
6. Sketch a wiring diagram for feeder circuits for motors.
7. Describe how a direct-current motor is made "fool proof" with regard to starting.
8. What is the office of the compensator in a 3-wire generator equipment?
9. Make a wiring diagram for a railway switchboard with direct-current feeders.
10. Describe a switchboard for an isolated plant where storage batteries are used.
11. Describe the operation of paralleling two alternators.
12. Make diagram of wiring for a small alternating-current industrial power board.
13. Discuss the requirements for large industrial power boards.
14. Discuss the subject of remote control as to its advisability, advantages, and different means of accomplishing it.
15. Make sketch of section through switchboard having remote control of oil switches.

REVIEW QUESTIONS

ON THE SUBJECT OF

STORAGE BATTERIES.

1. What is the lowest voltage to which a lead battery should be discharged?

2. What means may be employed to make up for the drop in potential of storage batteries during discharge?

3. What causes sulphating?

4. What plate of a storage battery is the positive?

5. Describe the several indications by which the amount of charge in a storage battery can be determined.

6. How is the capacity of a storage battery usually expressed?

7. What is an electrolyte?

8. What is meant by a floating battery, and when is it applicable?

9. How must a storage battery room be arranged?

10. What causes buckling?

11. Why are there always more negative plates than positive plates in a storage battery?

12. Give several applications of storage batteries.

13. When a storage battery is charged, what is found on the positive plate? What is found on the negative plate? What occurs when the cell is discharged?

14. What is the maximum voltage obtainable from a lead storage cell?

15. How may sulphating and buckling be prevented?

16. How would you put a battery out of commission for a long period, and how would you place it in service again?

17. What is the difference in construction between Faure and Planté plates?

18. What is the essential difference between a primary and a storage battery?

REVIEW QUESTIONS

ON THE SUBJECT OF

APPLIED ELECTROCHEMISTRY

1. How may chemical reactions be classified?

2. Which are the most important applications of electric energy to materials?

3. Into what classes are electric conductors divided?

4. Into what divisions may liquid conductors be divided?

5. Discuss the conductivity of water.

6. What is an electrochemical cell?

7. What is an anode; a cathode?

8. Define cathions and anions.

9. State Faraday's laws pertaining to electrolysis.

10. Define electrochemical equivalent.

11. What metal is commonly used to provide an insoluble metal anode?

12. Describe a simple experimental cell for refining copper.

13. What is electroplating?

14. Describe the arrangement of an electroplating cell.

15. At what voltage do electroplating dynamos run?

16. Discuss the adherence of metal deposits.

17. Discuss electroplating on non-conductive surfaces.

18. Give the chemical formula according to which the production of sodium hypochlorite takes place.

19. Compare the respective advantages of the diaphragm and mercury type of cells for the production of chlorine and caustic soda.

20. Give short descriptions of the different types of cells as used for the production of hydrogen and oxygen.

21. Describe the Hall process of producing aluminum.

22. What is an electric furnace?

23. Compare the heat efficiencies of the different kinds of furnaces.

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